Integrated Assessment Modelling for the Protocol to Abate Acidification, Eutrophication and Ground-level Ozone in Europe

Markus Amann
Imrich Bertok
Janusz Cofala
Frantisek Gyarfas
Chris Heyes
Zbigniew Klimont
Wolfgang Schöpp

Foreword

The somewhat long-winded name of the new ‘Protocol to Abate Acidification, Eutrophication and Ground-level Ozone’ illustrates the complex matter the Protocol is addressing. The international obligations laid down in the Protocol for controlling emissions of four substances - sulphur dioxide, nitrogen oxides, ammonia and volatile organic compounds - aim at maximum efficiency in reducing the three environmental problems mentioned in the title, taking into account interactions between the pollutants and between the effects.

The preparation of the Protocol took four years and about one thousand scientists and policymakers from all UN/ECE-countries were involved. Integrated assessment modelling, based on the so-called ‘critical loads and levels approach’, has been developed as a common concept for bringing together scientific information from many different disciplines and countries. The sensitivity of the ecosystems has been mapped all over Europe. Cost curves for each country have been formulated. With this information, IIASA's RAINS-model was used to find international emission ceilings that achieve the environmental goals selected by the negotiators in a cost-effective manner.

During the final negotiations in Geneva it turned out that, for a number of reasons, many countries could only accept less stringent national emission ceilings than originally envisaged when the negotiators agreed on a common environmental ambition level. Nevertheless, the negotiated ceilings will bring benefits to the environment in Europe; and this report clearly indicates this.

The aim of this report is to document the analysis of the main policy options conducted during the negotiations leading to the Protocol. It compares the negotiated ceilings with other scenarios discussed during the negotiations, it presents cost estimates and explores the environmental impacts of the various scenarios. Because this information is not provided in the official legal documents of the Protocol, I hope that this report will create transparency and inform the public, policy analysts and scientists about the background leading to the new agreement.

The report indicates too that there is certainly scope for further reduction of the ceilings laid down in the new Protocol. This encourages us to continue our efforts for clean air in Europe with even more energy, because now we are aware that we are working in the right direction.

ir. A.J. Baayen
Director
Directorate Air & Energy
Ministry of Housing, Spatial Planning and the Environment

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Authors	Markus Amann, Imrich Bertok, Janusz Cofala, Frantisek Gyarfas, Chris Heyes, Zbigniew Klimont, Wolfgang Schöpp of the International Institute for Applied Systems Analysis
Address to contact	Ministry of Housing, Spatial Planning and the Environment, Department for Air and Energy, ipc 640 P.O. Box 30945, 2500 GX The Hague The Netherlands

Summary

Countries that will ratify the 'Protocol to abate acidification, eutrophication and ground-level ozone' are committed to their national emission ceilings for SO_2, NO_x, VOC and NH_3 in 2010.

During the preparation of the Protocol a number of emission scenarios were developed. This report presents four of them and compares them with the situation in 1990:

- the reference scenario (REF) which has been constructed to assess likely environmental impacts of the current emission strategies in the year 2010
- the 'medium level ambition' scenario, used to guide the negotiations of the Protocol
- the hypothetical Maximum Feasible Reductions (MFR) scenario
- the negotiated ceilings of the new Protocol.

The report summarises the background data on economic, energy, transport and agricultural statistics for the base year 1990 and the projections for 2010. Using its integrated assessment model RAINS, the International Institute for Applied Systems Analysis (IIASA) assessed the costs of the scenarios and their environmental impacts for acidification, eutrophication and ground-level ozone.

Contents

1 INTRODUCTION

The aim of the Protocol to Abate Acidification, Eutrophication and Ground-level Ozone is to cut emissions of sulphur dioxide, nitrogen oxides, volatile organic compounds and ammonia in a cost-effective way to prevent adverse environmental and health effects. An Integrated Assessment Model based on the effects of each country's emissions and the costs of emission reduction measures guided the negotiations of emission reductions for each Party.

1.1 Integrated Assessment

The sensitivity of different ecosystems was a key factor in the modelling exercise, given the long-term goal of the Protocol to protect ecosystems from pollution. The critical load - the maximum amount of deposition an ecosystem can receive in the long-term without significant damage - varies considerably from one region to another according to soil and other conditions. Under this Protocol, critical load maps were drawn up for the whole of Europe by the Convention's Working Group on Effects.

The link between a country's emissions and the resulting environmental problem was also taken into consideration. In the case of acid deposition, the emissions from some sources may be deposited in areas with little or no deposition above the critical load. Countries in this situation will have to make relatively small emission cuts. Conversely, countries that contribute significantly to deposition exceeding critical loads will have to make larger cuts. The European monitoring and evaluation programme (EMEP) developed acid deposition patterns for each country's emissions, using atmospheric dispersion models and information from its extensive measurement network.

Eutrophication effects on ecosystems and ground-level ozone effects on both human health and vegetation were assessed in a similar manner.

Finally, costs were incorporated into the modelling. Where, for example, two countries contribute equally to excess deposition but the costs of taking action is much lower in one than in the other, the country with the lower costs will have to make greater emission cuts.

The process of combining all this information (critical loads, deposition patterns, abatement costs) to estimate the emission reductions required of each country is called "integrated assessment". In practice, this was done using a mathematical model that, depending on how ambitious countries wish to be in reducing excess deposition, estimates the national emission reductions that would fulfil the "ambition level" and gives the lowest costs for all the countries taken together.

1.2 The RAINS Model

During the negotiations on the Protocol to Abate Acidification, Eutrophication and Ground-level Ozone the Regional Air Pollution INformation and Simulation (RAINS)-model developed at the International Institute for Applied Systems Analysis (IIASA, Laxenburg, Austria) was used. The RAINS model provides a consistent framework for the analysis of emission reduction strategies, focusing on acidification, eutrophication and tropospheric ozone. RAINS comprises modules for emission generation (with databases on current and future economic activities, energy consumption levels, fuel characteristics, etc.), for emission control options and costs, for atmospheric dispersion of pollutants and for environmental sensitivities (i.e., databases on critical loads). In order to create a consistent and comprehensive picture of the options for simultaneously addressing the three environmental problems (acidification, eutrophication and tropospheric ozone), the model considers emissions of sulphur dioxide (SO_2), nitrogen oxides

(NO_x), ammonia (NH_3) and volatile organic compounds (VOC). A detailed description of the RAINS model can be found in Amann *et al.*, 1998. A schematic diagram of the RAINS model is displayed in Figure 1.1.

The European implementation of the RAINS model incorporates databases on energy consumption for 38 regions in Europe, distinguishing 22 categories of fuel use in six economic sectors. The time horizon extends from the year 1990 up to the year 2010. Emissions of SO_2, NO_x, NH_3 and VOC for 1990 are estimated based on information collected by the CORINAIR'90 inventory of the European Environmental Agency (EEA, 1996) and on national information. Options and costs for controlling emissions of the various substances are represented in the model by considering the characteristic technical and economic features of the most important emission reduction measures. Atmospheric dispersion processes over Europe for sulphur and nitrogen compounds are modelled based on results of the European EMEP model developed at the Norwegian Meteorological Institute (Barret and Sandnes, 1996). For tropospheric ozone, source-receptor relationships between the precursor emissions and the regional ozone concentrations are derived from the EMEP photo-oxidants model (Heyes and Schöpp, 1997; Simpson, 1993). The RAINS model incorporates databases on critical loads and critical levels compiled at the Coordination Center for Effects (CCE) at the National Institute for Public Health and Environmental Protection (RIVM) in the Netherlands (Posch *et al.*, 1999).

The RAINS model can be operated in the 'scenario analysis' mode, i.e., following the pathways of the emissions from their sources to their environmental impacts. In this case the model provides estimates of regional costs and environmental benefits of alternative emission control strategies. Alternatively, an 'optimisation mode' is available to identify cost-optimal allocations of emission reductions in order to achieve specified environmental targets.

The full documentation of the RAINS model, its databases and an on-line version of the model are available on the Internet (http://www.iiasa.ac.at/~rains).

During the negotiations on the Protocol to Abate Acidification, Eutrophication and Ground-level Ozone the RAINS model was first used to explore the possible range for environmental improvements between what is expected to be achieved by current legislation and what could be achieved if technical emission controls were utilised to the maximum extent. Later during the negotiations, the model was used to identify cost-minimal distributions of emission reductions across the countries to reach the environmental targets specified by the negotiating Parties and, vice versa, to illustrate the environmental impacts of emission reductions proposed by the negotiators.

At its 28th Session in January 1999, the UN/ECE Working Group on Strategies selected the 'G5/2' scenario, presented at the 22nd meeting of the Task Force on Integrated Assessment Modelling, as the guiding scenario for the negotiations. It must be noted that while the model results strongly guided the negotiations, the commitments made by the Parties were also influenced by domestic considerations.

1.3 Structure of the Report

The purpose of the present report is to provide quantitative information on a number of scenarios calculated for the Protocol negotiations, in order to assist in the assessment of the costs involved and of the effectiveness of the Protocol with respect to human health and the environment.

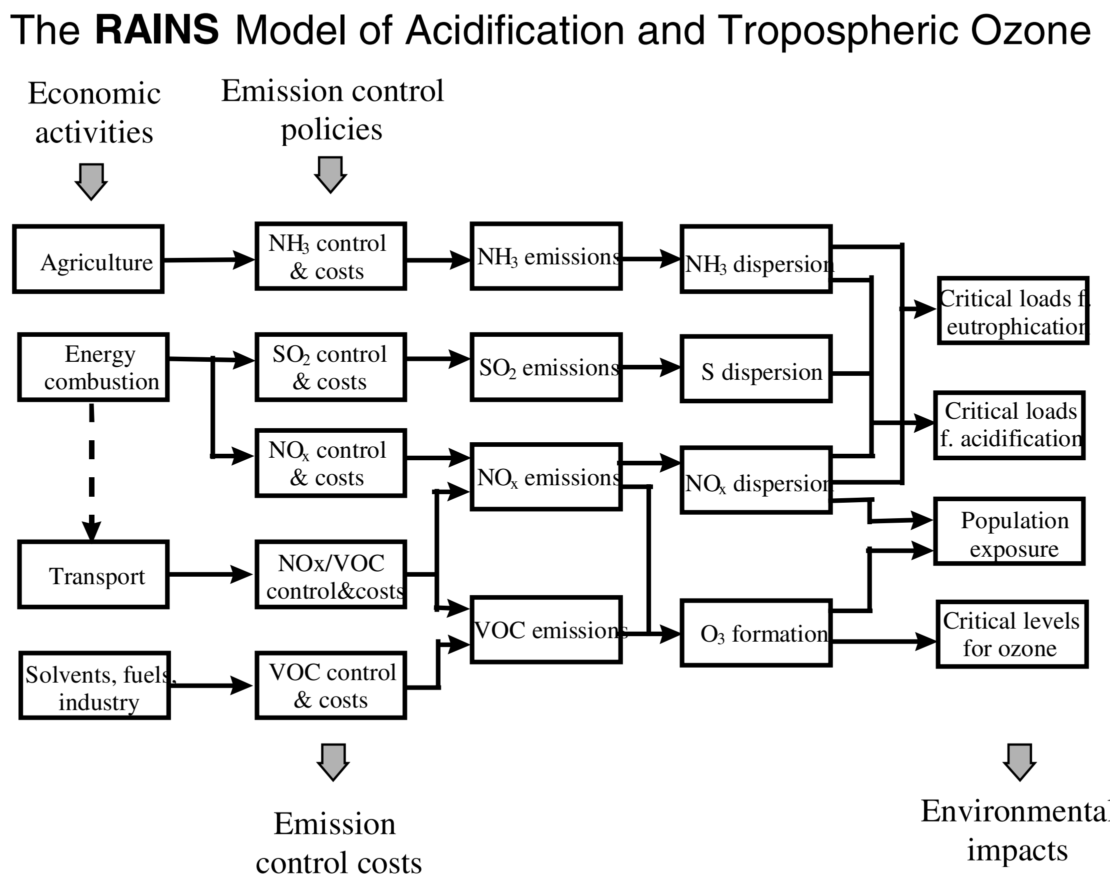


Figure 1.1: Schematic flowchart of the RAINS model framework

Five emission scenarios are presented:

- the situation in 1990;
- a Reference scenario (REF) which has been constructed to assess the likely environmental impacts of the current emission control strategies in the year 2010;
- the revised 'medium level ambition' scenario G5/2 ($G5/2_{rev}$), selected by the negotiators as the guiding scenario;
- a hypothetical Maximum Feasible Reductions scenario, which illustrates the potential of full application of the most efficient current control technologies to the entire range of emission sources (MFR_{ult}), and
- the final commitments accepted by the Parties in the Protocol to Abate Acidification, Eutrophication and Ground-level Ozone.

Section 2 gives general background data on economic, energy, transport and agricultural statistics for the 1990 situation and projections for 2010. Maps showing the spatial distribution of the two-percentile critical loads for acidification and eutrophication are also provided. The emissions and costs associated with the scenarios are summarised in Section 3. Finally, Section 4 covers the environmental impacts expected to result from the five scenarios. For each of the problem areas considered – acidification, eutrophication and ozone – the environmental consequences are compared using several different indicators.

2 BACKGROUND DATA

2.1 General Economic Data 1990

Table 2.1: Population statistics, gross domestic product (GDP) expressed in purchasing power parity, consumption of total primary energy and transport statistics (passenger cars and light duty vehicles (LDV), motorcycles and heavy duty vehicles) for the year 1990

	Population [millions]	GDP [billion EURO]	Total primary energy [PJ]	Passenger cars and LDV [1000]	Motorcycles [1000]	Heavy duty vehicles [1000]
Austria	7.72	101.9	1242	3167	535	86
Belgium	9.96	131.1	1907	3966	515	157
Denmark	5.14	69.3	731	1833	181	71
Finland	4.99	63.9	1233	2131	170	67
France	56.42	775.5	9122	26580	3879	532
Germany	79.37	1006.7	14534	36287	4282	1335
Greece	10.12	72.9	923	2221	489	190
Ireland	3.51	31.5	409	940	15	26
Italy	57.66	739.4	6676	27765	4221	1032
Luxembourg	0.38	6.8	122	191	10	6
Netherlands	14.95	187.7	2737	5716	955	170
Portugal	9.36	78.4	699	2462	1849	587
Spain	38.96	362.4	3612	13106	2870	1025
Sweden	8.56	115.4	2430	3824	114	100
UK	57.41	717.5	8544	22470	1936	467
EU-15	364.50	4460.5	54920	152660	22022	5852
Albania	3.26	5.7	128	17	8	32
Belarus	10.26	55.6	1762	740	400	172
Bosnia-H.	4.42	8.1	311	443	15	46
Bulgaria	9.00	36.4	1310	1349	507	120
Croatia	4.50	17.4	413	801	20	46
Czech Rep.	10.36	90.4	1949	2411	719	182
Estonia	1.58	12.0	423	253	103	59
Hungary	10.37	58.4	1109	2083	370	96
Latvia	2.69	20.9	399	295	195	67
Lithuania	3.72	18.1	677	507	196	73
Norway	4.23	58.7	1426	1853	168	85
Poland	38.18	159.9	4250	5775	1357	622
Moldova	4.36	19.9	392	211	190	20
Romania	23.21	72.4	2425	1335	312	338
Russia	102.75	719.7	18237	8114	8800	1747
Slovakia	5.31	36.6	987	898	286	83
Slovenia	1.97	14.4	231	588	16	24
Switzerland	6.75	114.0	1119	3182	764	62
FYR Macedonia	2.08	3.9	151	236	3	18
Ukraine	51.84	251.2	9970	3413	2500	805
Yugoslavia	10.55	28.7	790	1505	34	73
Non-EU	311.39	1802.3	48458	36011	16963	4772
Total	675.89	6262.8	103378	188671	38985	10624

Table 2.2: Agricultural statistics for 1990

	Cattle	Pigs	Poultry	Fertiliser use
	[million animals]			[1000 tons N]
Austria	2.6	3.7	13.8	137
Belgium	3.1	6.4	23.6	166
Denmark	2.2	9.3	16.2	395
Finland	1.4	1.4	9.5	228
France	21.4	5.9	271.7	2576
Germany	19.5	30.8	113.9	2200
Greece	0.7	1.0	27.7	428
Ireland	7.0	1.0	9.0	370
Italy	7.8	6.9	173.3	879
Luxembourg	0.2	0.1	0.1	20
Netherlands	4.9	13.9	93.8	404
Portugal	1.3	2.7	31.2	150
Spain	5.1	16.0	44.9	1064
Sweden	1.7	2.3	12.6	212
UK	12.1	7.5	136.4	1516
EU-15	91.2	108.8	978.0	10745
Albania	0.6	0.2	5.0	73
Belarus	7.2	5.2	49.8	780
Bosnia-H.	0.9	0.6	9.0	19
Bulgaria	1.6	4.4	36.3	453
Croatia	0.8	1.6	15.0	114
Czech Rep.	3.4	4.6	33.3	370
Estonia	0.8	1.1	7.0	110
Hungary	1.6	9.7	58.6	359
Latvia	1.5	1.6	11.0	143
Lithuania	2.4	2.7	18.0	256
Norway	1.0	0.7	5.4	111
Poland	10.0	19.5	70.0	671
Moldova	1.1	2.0	25.0	123
Romania	6.3	11.7	119.3	765
Russia	42.2	30.5	474.3	3418
Slovakia	1.5	2.5	16.5	217
Slovenia	0.5	0.6	13.5	88
Switzerland	1.9	1.8	6.5	63
FYR Macedonia	0.3	0.2	22.0	6
Ukraine	25.2	19.9	255.1	1885
Yugoslavia	2.2	4.3	28.0	146
Non-EU	113.0	125.4	1279.0	10170
Total	204.2	234.2	2256.0	20915

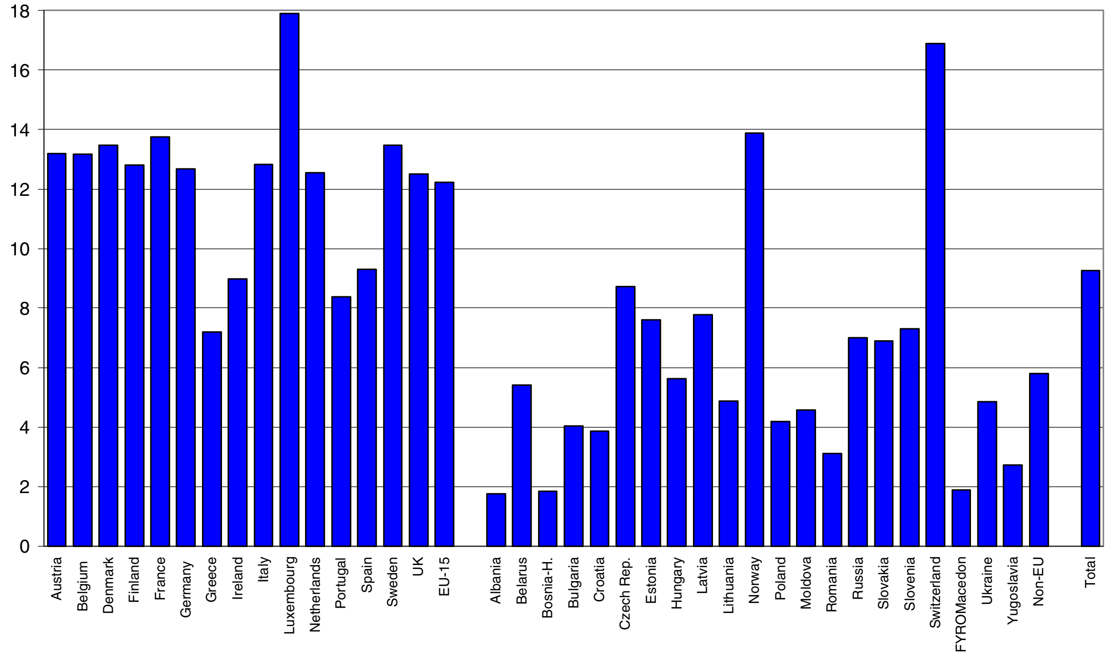


Figure 2.1: Gross domestic product per capita in 1990 (1000 Euro/person)

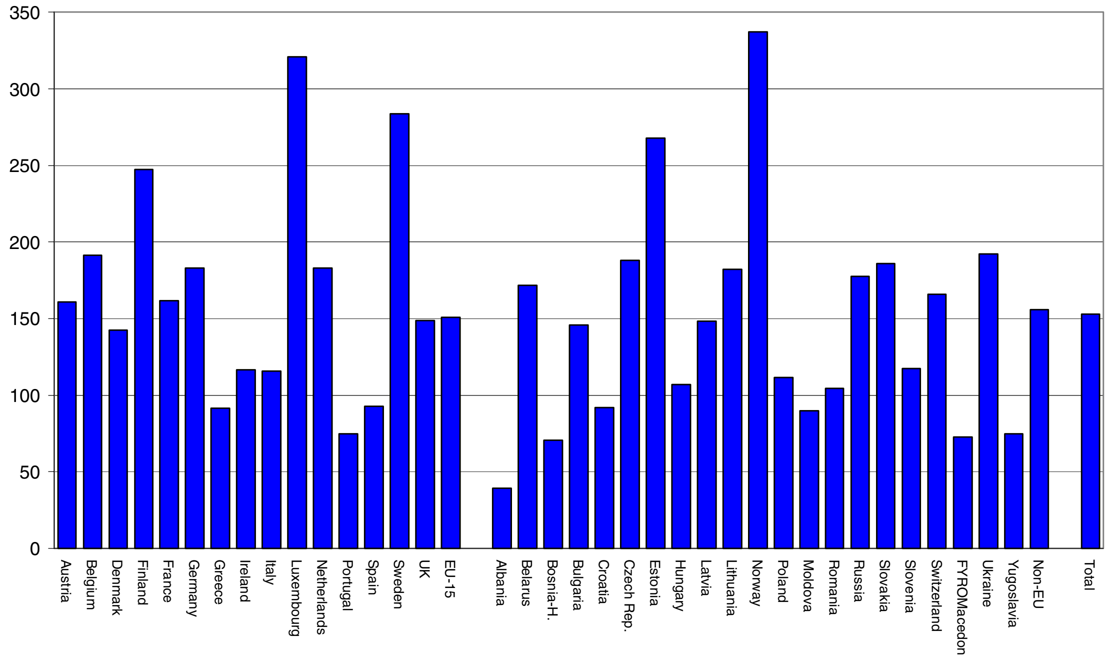


Figure 2.2: Per-capita consumption of total primary energy in the year 1990 (GJ/person)

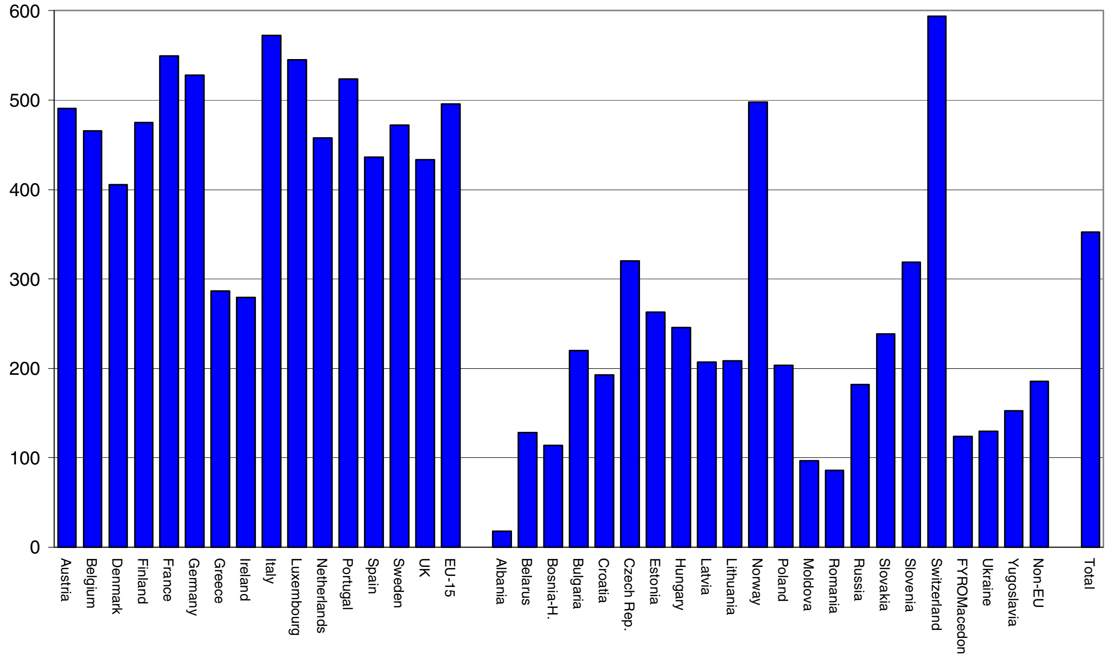


Figure 2.3: Number of cars per 1000 persons in 1990

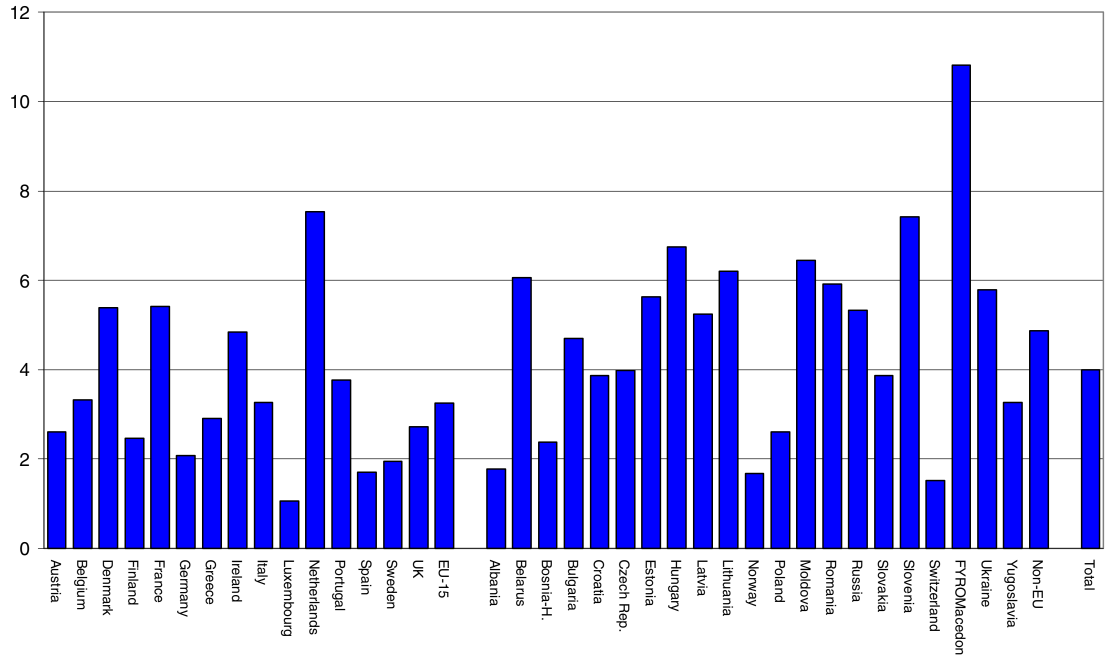


Figure 2.4: Number of animals per capita in 1990

2.2 Projected Data for 2010

Table 2.3: Projection of economic, energy and transport statistics for the year 2010

	Population		GDP		Energy		Vehicles	
	Million persons 2010	Change 1990-2010	Billion EURO 2010	Change 1990-2010	PJ 2010	Change 1990-2010	1000 vehicles 2010	Change 1990-2010
Austria	8.23	*6.7%*	158.4	*46%*	1421	*14%*	5813	*53%*
Belgium	9.96	*0.0%*	198.9	*52%*	2436	*28%*	6729	*45%*
Denmark	5.27	*2.6%*	110.0	*55%*	783	*7%*	2391	*15%*
Finland	5.29	*6.1%*	122.2	*81%*	1615	*31%*	3159	*33%*
France	62.20	*10.2%*	1266.4	*49%*	11128	*22%*	43100	*39%*
Germany	83.59	*5.3%*	1663.8	*58%*	14176	*-2%*	56785	*36%*
Greece	10.75	*6.2%*	135.5	*74%*	1813	*97%*	6550	*126%*
Ireland	3.58	*2.2%*	79.1	*146%*	698	*71%*	2348	*139%*
Italy	57.80	*0.2%*	1081.5	*46%*	8444	*26%*	41220	*25%*
Luxembourg	0.38	*0.6%*	10.8	*58%*	129	*6%*	278	*34%*
Netherlands	16.50	*10.4%*	398.2	*91%*	3713	*36%*	10462	*53%*
Portugal	9.49	*1.3%*	129.9	*81%*	1112	*59%*	7251	*48%*
Spain	40.57	*4.1%*	631.2	*67%*	5215	*44%*	27262	*60%*
Sweden	9.12	*6.5%*	180.2	*47%*	2581	*6%*	5709	*41%*
UK	60.22	*4.9%*	1190.3	*58%*	9875	*16%*	36803	*48%*
EU-15	382.96	*5.1%*	7341.2	*57%*	65141	*19%*	255861	*42%*
Albania	4.10	*25.9%*	9.5	*35%*	143	*12%*	292	*413%*
Belarus	10.00	*-2.5%*	60.2	*10%*	1553	*-12%*	2255	*72%*
Bosnia-H.	4.40	*-0.5%*	7.8	*-6%*	297	*-5%*	552	*10%*
Bulgaria	8.20	*-8.9%*	40.5	*22%*	1276	*-3%*	2637	*33%*
Croatia	4.40	*-2.2%*	22.4	*32%*	447	*8%*	1175	*35%*
Czech Rep.	10.40	*0.4%*	125.4	*37%*	1764	*-10%*	4630	*40%*
Estonia	1.49	*-5.7%*	12.3	*10%*	366	*-13%*	619	*49%*
Hungary	9.66	*-6.8%*	76.0	*40%*	1350	*22%*	3962	*55%*
Latvia	2.44	*-9.3%*	15.1	*-20%*	359	*-10%*	764	*37%*
Lithuania	3.74	*0.5%*	15.9	*-13%*	565	*-17%*	1039	*34%*
Norway	4.41	*4.3%*	90.6	*49%*	1904	*34%*	2582	*23%*
Poland	40.00	*4.8%*	303.2	*81%*	5253	*24%*	15473	*100%*
Moldova	4.80	*10.1%*	13.9	*-36%*	324	*-17%*	547	*30%*
Romania	22.30	*-3.9%*	88.3	*27%*	2525	*4%*	2760	*39%*
Russia	99.56	*-3.1%*	643.3	*-8%*	16617	*-9%*	25262	*35%*
Slovakia	5.70	*7.3%*	51.9	*32%*	982	*0%*	1871	*48%*
Slovenia	1.91	*-3.0%*	27.9	*103%*	234	*1%*	848	*35%*
Switzerland	7.60	*12.6%*	165.1	*29%*	1184	*6%*	6005	*50%*
FYR Macedonia	2.36	*13.5%*	5.1	*10%*	138	*-9%*	288	*12%*
Ukraine	50.10	*-3.4%*	199.5	*-18%*	8559	*-14%*	9247	*38%*
Yugoslavia	11.10	*5.2%*	35.3	*13%*	725	*-8%*	1766	*10%*
Non-EU	308.67	*-0.9%*	1995.2	*11%*	46567	*-4%*	84573	*46%*
Total	691.63	*2.3%*	9336.4	*42%*	111707	*8%*	340434	*43%*

Table 2.4: Projection of livestock (million animals) and fertiliser use (1000 tons N) up to the year 2010

	Cattle		Pigs		Poultry		Fertiliser use	
	2010		2010		2010		2010	
Austria	2.2	*-15%*	3.4	*-7%*	12	*-13%*	109	*-20%*
Belgium	2.8	*-11%*	7.2	*12%*	40.3	*71%*	137	*-17%*
Denmark	1.7	*-23%*	11.7	*26%*	17.4	*7%*	261	*-34%*
Finland	0.9	*-33%*	1.4	*-2%*	8.1	*-14%*	180	*-21%*
France	19.9	*-7%*	8.3	*42%*	317.3	*17%*	2457	*-5%*
Germany	15.7	*-19%*	21.2	*-31%*	78.6	*-31%*	1801	*-18%*
Greece	0.6	*-20%*	1.2	*21%*	33	*19%*	294	*-31%*
Ireland	7.4	*6%*	2.2	*110%*	13.2	*46%*	357	*-4%*
Italy	7	*-11%*	6.5	*-7%*	184	*6%*	919	*5%*
Luxembourg	0.4	*78%*	0.1	*-33%*	0.1	*-28%*	16	*-20%*
Netherlands	4.8	*-2%*	11.2	*-20%*	79.5	*-15%*	291	*-28%*
Portugal	1.3	*-2%*	2.2	*-17%*	33.6	*8%*	144	*-4%*
Spain	6	*17%*	20.3	*27%*	83.1	*85%*	1052	*-1%*
Sweden	1.8	*5%*	2.4	*4%*	12.6	*0%*	199	*-6%*
UK	10.4	*-14%*	7.8	*5%*	141	*3%*	1298	*-14%*
EU-15	82.9	*-8%*	106.9	*1%*	1054	*8%*	9515	*-11%*
Albania	0.8	*21%*	0.3	*17%*	8.4	*68%*	60	*-18%*
Belarus	4.3	*-40%*	4	*-23%*	43.3	*-13%*	676	*-13%*
Bosnia -H	0.7	*-22%*	0.6	*-10%*	8	*-11%*	10	*-47%*
Bulgaria	0.9	*-41%*	4.3	*-2%*	43.6	*20%*	530	*17%*
Croatia	0.6	*-27%*	1.3	*-17%*	8.4	*-44%*	190	*67%*
Czech Rep.	3.4	*3%*	5.8	*26%*	49.1	*48%*	350	*-5%*
Estonia	0.6	*-28%*	1.2	*9%*	7.8	*11%*	151	*37%*
Hungary	1.6	*-3%*	7.9	*-19%*	63.5	*8%*	639	*78%*
Latvia	0.7	*-52%*	1.5	*-7%*	7.6	*-31%*	221	*55%*
Lithuania	2.2	*-7%*	2.8	*2%*	19.2	*7%*	309	*21%*
Norway	0.7	*-25%*	0.8	*10%*	5.3	*-2%*	92	*-17%*
Poland	12.9	*28%*	23.8	*22%*	97.8	*40%*	855	*27%*
R. Moldova	1	*-13%*	1.5	*-27%*	19	*-24%*	228	*85%*
Romania	6.2	*-2%*	10.3	*-12%*	146.8	*23%*	780	*2%*
Russia	27.3	*-35%*	30.5	*0%*	326.5	*-31%*	1994	*-42%*
Slovakia	0.8	*-44%*	2.6	*2%*	22	*34%*	180	*-17%*
Slovenia	0.4	*-22%*	0.7	*18%*	12.9	*-4%*	103	*17%*
Switzerland	1.7	*-8%*	1.4	*-22%*	6.5	*0%*	30	*-52%*
FYR Maced.	0.3	*-1%*	0.2	*7%*	22	*0%*	3	*-50%*
Ukraine	20.5	*-19%*	23	*15%*	260	*2%*	1599	*-15%*
Yugoslavia	2	*-8%*	4.1	*-5%*	21	*-25%*	145	*-1%*
Non-EU	89.6	*-21%*	128.3	*2%*	1199	*-6%*	9145	*-10%*
Total	172.5	*-15%*	235.2	*2%*	2253	*0%*	18660	*-11%*

2.3 Environmental Sensitivities

2.3.1 Acidification

Once deposited on the earth after their long-range transport in the atmosphere, emissions of sulphur dioxide (SO_2), nitrogen oxides (NO_x) and ammonia (NH_3) act as acidifying agents in soils and lakes. Several natural mechanisms (e.g., mineral weathering, deposition of alkaline dust, etc.) may neutralise a certain fraction of the acidifying deposition, depending on the type of the ecosystems and on a range of site-specific conditions (climate, hydrology, etc.). If acid deposition exceeds this natural absorption capacity, resulting changes in soil and water chemistry will lead to damage to plants and aquatic life.

The threshold "below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge" is called the "critical load" (Nilsson and Grennfelt, 1988). In an effort co-ordinated by the UN/ECE Convention on Long-range Transboundary Air Pollution, all European countries estimated the critical loads for their domestic ecosystems. These national estimates were combined into a European critical loads database by the Coordination Center for Effects at the Netherlands Institute for Public Health and the Environment (Posch *et al.,* 1999).

For the 1999 version of the critical loads databases, the number of countries which submitted data has increased to 24. National focal centres have selected in total 1,314,806 ecosystems as receptors for calculating and mapping critical loads. For those countries which did not provide their national critical loads estimates to the CCE, the European background database for critical loads (Posch *et al.,* 1999) is employed. The European background database is constructed at the CCE by applying the consensus methodology for calculating critical loads to internationally published information, such as the 1994 digital soil map of the FAO and the RIVM European land use maps.

The European critical loads database as compiled by the Coordination Center for Effects provides for each cell of the EMEP grid system the cumulative distribution function of the critical loads for all ecosystems of the grid cell. From this information it is possible to derive for each grid cell, for a given deposition value calculated from a certain emission control scenario, (a) the excess deposition for a selected ecosystem (e.g., for the two percentile), (b) the percentage of ecosystems which experience deposition below their critical loads (i.e., the ecosystems protected against acidification), and (c) the accumulated acid deposition in excess of the critical loads for all ecosystems in a grid cell. Figure 2.5 displays the two percentile of the critical loads database for acidification, i.e., the maximum deposition at which 98 percent of the ecosystems are protected.

The first two measures have been used in the past to establish environmental interim targets on the way towards the full achievement of critical loads. The negotiations on the Second Sulphur Protocol of the Convention on Long-range Transboundary Air Pollution postulated for each grid cell a minimum '60 percent gap closure' between the deposition in 1980 and the critical load of the 'five percentile' ecosystem. This strategy relied only on the critical load estimate of one single ecosystem, i.e., it ignored the five percent more sensitive ecosystems and the 94 percent less sensitive ecosystems in each grid cell. The EU Acidification Strategy used the second approach targeting the percentage of protected ecosystems as the key environmental indicator for shaping the strategy. The analysis for the Protocol on Acidification, Eutrophication and Ground-level Ozone used the third concept, i.e., the total excess deposition (above the critical loads) accumulated for all ecosystems in a grid cell.

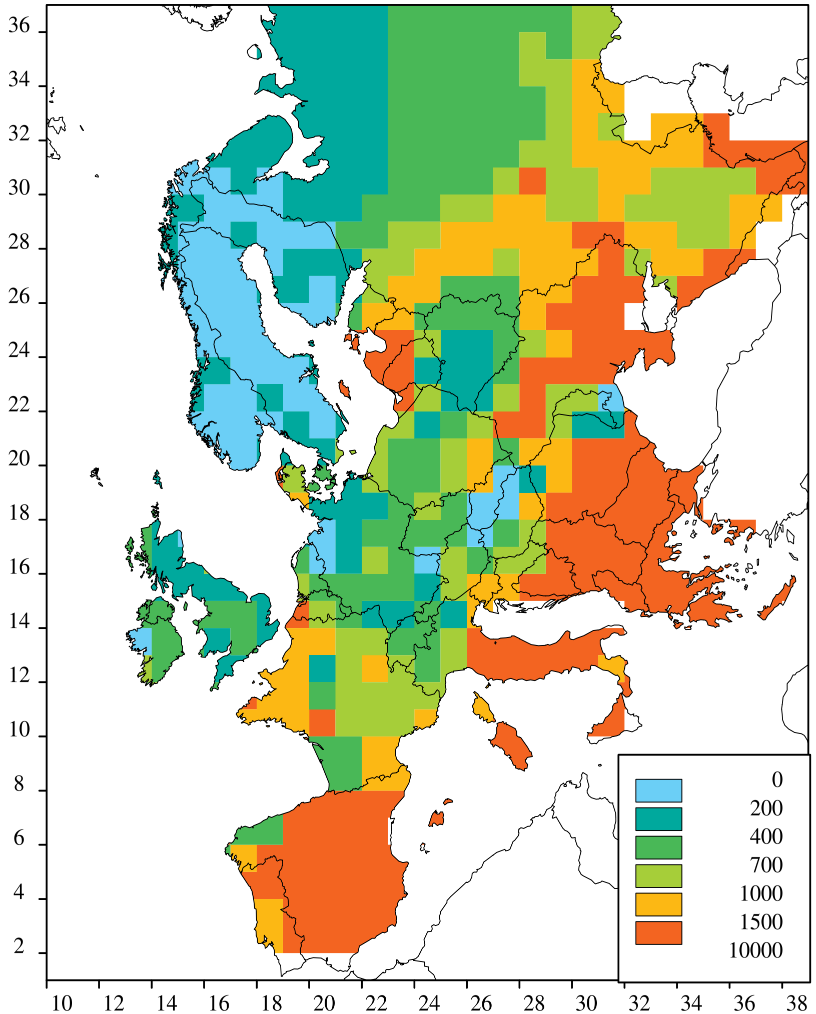


Figure 2.5: The 2-percentile critical load for acidification ($CL_s max$) (equivalents/ha/year)

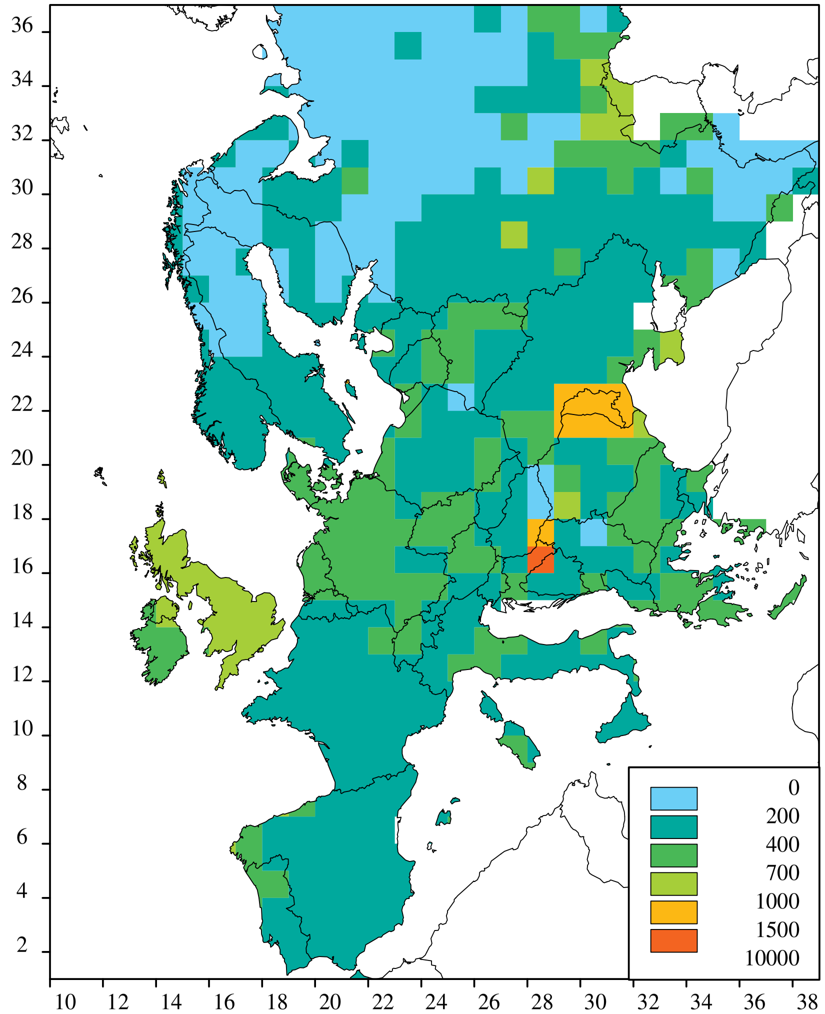


Figure 2.6: The 2-percentile critical load for eutrophication (equivalents/ha/year)

2.3.2 Eutrophication

In sensitive areas, high levels of nitrogen deposition from nitrogen oxides and ammonia emissions result in eutrophication. The increase of this plant nutrient in natural ecosystems causes some plant species to grow excessively and others to disappear. In coastal and inland waters, blooms of algae deplete oxygen, affecting plants, fish and other life forms. Greater nitrogen deposition directly increases nitrate concentrations in groundwater normally used for drinking and also causes nitrogen to leach from soils, increasing the acidification of surface and ground waters. In analogy to acidification, critical loads for eutrophication, indicating the maximum deposition of nitrogen not causing harmful effects in the long run, were estimated by all European countries. The two-percentile of the critical loads database for eutrophication is presented in Figure 2.6.

2.3.3 Ground-level Ozone

Ground-level ozone has significant impacts on human health and vegetation. It affects lung function, particularly in children and asthmatics, either from short-term exposure to high ozone levels or from longer exposure to lower levels. Ozone also causes leaf injury in plants, including crops and trees, significantly reducing plant growth and crop yield, and causes some materials - particularly organic materials such as paints and rubber - to disintegrate.

Ozone is a secondary pollutant formed in the atmosphere in the presence of sunlight from the precursor emissions nitrogen oxides (NO_x) and volatile organic compounds (VOC). Due to the long atmospheric residence time of NO_x and VOC compounds, ozone is created both from local emissions as well as from the precursors emitted at distant locations.

The model analyses carried out for the Protocol on Acidification, Eutrophication and Ground-level ozone address the protection of human health and vegetation against elevated ozone exposure.

In the absence of accepted dose-response curves applicable at the large scale, the analysis in this report uses the concept of critical thresholds as developed within the framework of the UN/ECE Convention on Long-range Transboundary Air Pollution. The Working Group on Effects of this Convention established two long-term related critical levels:

- For agricultural crops and herbaceous plant communities (natural vegetation), the critical level is set at an AOT40 of 3 ppm.hours for the growing season and daylight hours, over a five-year period;
- For forest trees, a critical level of 10 ppm.hours for daylight hours, accumulated over a six-month growing season, is proposed.

The AOT40 is calculated as the sum of the differences between the hourly ozone concentrations in ppb and 40 ppb for each hour when the concentration exceeds 40 ppb, using daylight hours only.

It has been shown elsewhere that for the currently prevailing European ozone regime the critical level for crops and natural vegetation is stricter than the critical level for forest trees. This means in other words, while the critical levels for forest trees are usually met when the critical level for crops and vegetation is achieved, the opposite statement does not hold. Based on this finding it has been decided to restrict the scenario analysis to the critical levels for crops and natural vegetation.

For summarising the main differences in ozone exposure between emission scenarios, two vegetation-related exposure indices were defined. The cumulative vegetation exposure index is calculated as the excess AOT40 (i.e., the AOT40 in excess of the critical level of 3 ppm.hours) multiplied by the area of ecosystems that is exposed to the excess concentration. The index is calculated on a grid resolution, considering agricultural land, natural vegetation and forest areas. The average vegetation exposure index reflects the average excess AOT40 (over all grids in a country). The estimate of these indices is based on rural ozone concentrations.

For the protection of human health the revised Air Quality Guidelines for Europe of the World Health Organisation propose a maximum concentration of 60 ppb as an eight-hour moving average. The ultimate goal would be to eliminate all excess of this criterion.

The modelling of European abatement strategies for individual days over a multi-month period is a rather ambitious task and is not entirely feasible at the moment. In order to simplify the modelling task, the target of no-exceedance of the WHO criterion (60 ppb as maximum eight-hour mean concentrations) was converted into an AOT index, which could be handled in a similar way to the AOT40 for vegetation. As a result, an AOT60 (i.e., the cumulative excess exposure over 60 ppb, for practical reasons over a six-month period) of zero is considered as equivalent to the full achievement of the WHO criterion. Any violation of this WHO guideline will consequently result in an AOT60 of larger than zero.

It is important to stress that this AOT60 surrogate indicator has been introduced purely for practical modelling reasons. Given the current knowledge on health effects it is not possible to link any AOT60 value larger than zero with a certain risk to human health. The only possible interpretation is that if the AOT60 is above zero, the WHO criterion is exceeded at least once during the six-month period.

This report provides two different indices of population exposure for the AOT60. The cumulative index reflects for each country the total exposure of a population and is expressed in person.ppm.hours. The RAINS model calculates these indices on a grid basis (using gridded data on AOT60 and population); in a second step these grid values are aggregated to the country level. The indices presented in this report use the AOT60 concentrations per grid, representing the rural ozone concentrations, and the total population per grid in 1990. Inaccuracies may occur for grids with major urban areas, where the rural ozone concentrations used for this analysis present an upper bound for the concentrations in the cities, and are lower than the concentrations occurring in the city plumes. The 'average' indicator reflects the average exposure of a person in a country, calculated from gridded data. It is important to stress that these indices may not be used to derive estimates of health damage, for which more detailed information is deemed necessary. In the context of this report, these indices provide relative measures to enable a quick comparison of different scenarios.

3 EMISSIONS AND CONTROL COSTS

The emissions of NO_x for the four scenarios are presented in Table 3.1. For Europe as a whole, the REF scenario results in a 38 percent cut of NO_x compared to the 1990 emission level, the revised G5/2 scenario requires a 45 percent reduction, while the MFR_{ult} scenario would result in a decrease in European NO_x of some 80 percent. For the Protocol, agreement was reached on a 40 percent cut.

Table 3.2 shows the VOC emissions. The REF scenario results in a 37 percent cut of VOC emissions across Europe. The revised G5/2 scenario requires further reductions beyond REF (45 percent reduction compared to 1990), and the MFR_{ult} scenario would result in a cut of 75 percent. The Protocol obligations imply a 40 percent decline in VOC emissions.

Emissions of SO_2 are given in Table 3.3. The REF scenario implies a 62 percent decrease of SO_2 emissions across all European countries. In order to achieve the environmental targets of the revised G5/2 scenario, SO_2 emissions would be reduced further, requiring a cut of 73 percent (compared to 1990), while the actual commitments in the Protocol mean a 63 percent reduction. The hypothetical MFR_{ult} scenario would result in a decrease in European SO_2 of 90 percent.

The NH_3 emissions are tabulated in Table 3.4. The overall reduction in the REF scenario is about 12 percent compared to 1990, and it is evenly distributed between EU and non-EU countries. In many countries reductions are achieved due to a decline in the number of animals projected for 2010. The guiding G5/2rev scenario proposes a cut in ammonia emissions by 24 percent, while the Parties agreed in the Protocol to a 17 percent reduction. The MFR_{ult} scenario achieves a 42 percent reduction.

Maps illustrating the spatial distribution of emission densities of the four pollutants are shown in Figure 3.1-Figure 3.8.

Table 3.5 presents control costs for the NO_x and VOC reductions, given jointly for NO_x and VOC because control technologies used in the transport sector simultaneously reduce the emissions of the two pollutants. Emission control costs for NO_x and VOC emissions in the REF scenario amount to 53 billion EURO/year, out of which 47 billion emerge in the EU-15 countries. The costs of the further emission reductions implied by the Protocol are estimated at 1.1 billion EURO/year, while the envisaged $G5/2_{rev}$ scenario implied additional costs of 3.2 billion EURO/year above those of REF. The total costs of NO_x and VOC reductions in the MFR_{ult} scenario amount to more than 110 billion EURO/year.

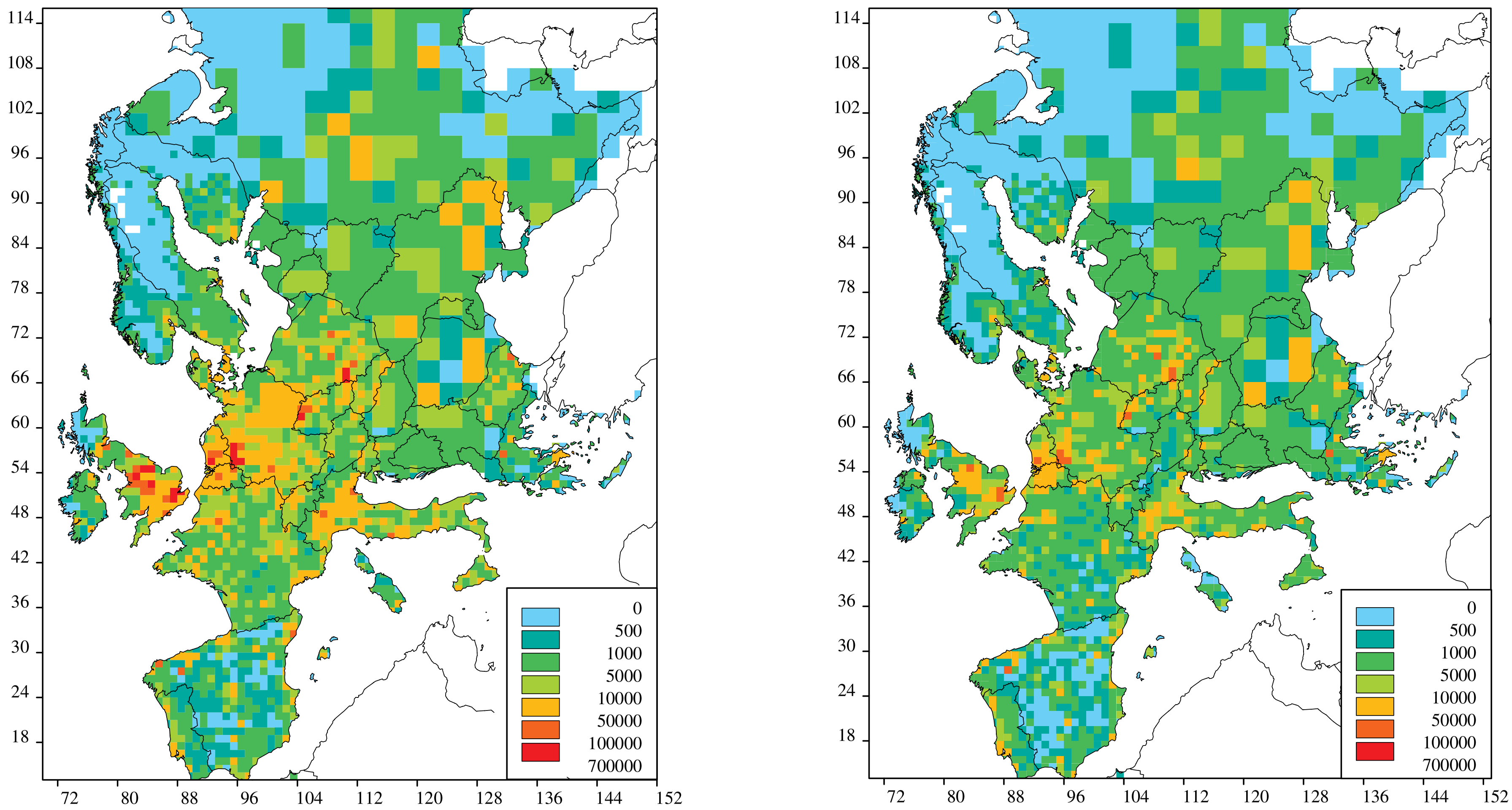
The control costs for SO_2 and NH_3 are presented in Table 3.6 and Table 3.7. In the REF scenario SO_2 control costs reach 14 billion EURO/year; those for ammonia are less than 0.5 billion EURO/year .For the Protocol, additional costs of 0.36 and 1.22 billion EURO/year are calculated for SO_2 and NH_3, respectively. The additional costs of the revised G5/2 scenario amount to 1.8 and 3.4 billion EURO/year. For SO_2, the maximum achievable emission reductions for entire Europe in the MFR_{ult} scenario would cost about 24 billion EURO/year. For ammonia, the corresponding cost would be 22 billion EURO/year.

The total emission control costs for all pollutants are summarised in Table 3.8. The revised G5/2 scenario would increase total emission control costs from 67 billion EURO/year in the REF scenario to 75.5 billion EURO/year for Europe as a whole, while the Protocol reached agreement on 70 billion EURO/year. The total costs of the MFR_{ult} scenario would amount to about 157 billion EURO/year

3.1 NOx Emissions

Table 3.1: Emissions of NO_x for 1990 and the Reference (REF), Protocol, revised G5/2 and hypothetical maximum technically feasible reductions (MFR_{ult}) scenarios (in kilotons). Percentage changes relate to the year 1990.

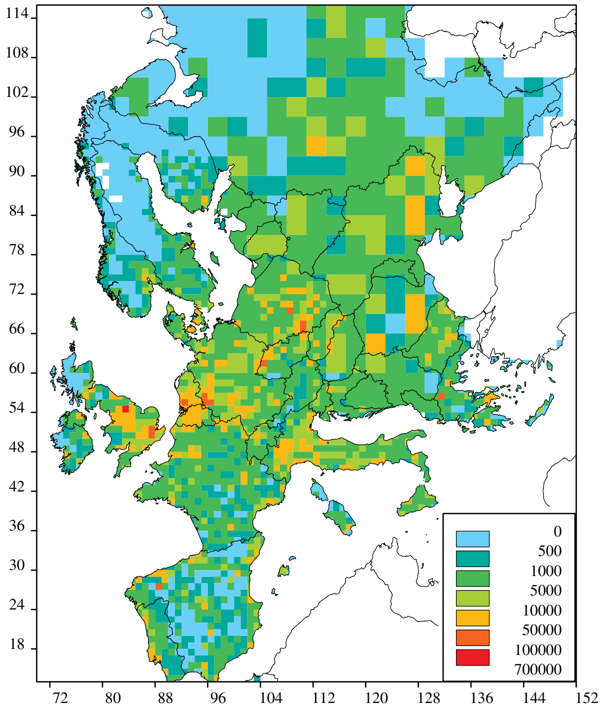
	1990	REF		Protocol		G5/2rev		MFR_{ult}	
	kt	kt	Change	kt	Change	kt	Change	kt	Change
Austria	192	103	-46%	107	-44%	91	-53%	54	-72%
Belgium	351	191	-46%	181	-48%	127	-64%	81	-77%
Denmark	274	128	-53%	127	-54%	113	-59%	49	-82%
Finland	276	152	-45%	170	-38%	152	-45%	56	-80%
France	1867	858	-54%	860	-54%	704	-62%	383	-79%
Germany	2662	1184	-56%	1081	-59%	1081	-59%	622	-77%
Greece	345	344	0%	344	0%	344	0%	127	-63%
Ireland	113	70	-38%	65	-42%	55	-51%	27	-76%
Italy	2037	1130	-45%	1000	-51%	901	-56%	396	-81%
Luxembourg	22	10	-55%	11	-50%	8	-64%	4	-80%
Netherlands	542	280	-48%	266	-51%	266	-51%	127	-77%
Portugal	208	177	-15%	260	25%	144	-31%	51	-76%
Spain	1162	847	-27%	847	-27%	726	-38%	263	-77%
Sweden	338	190	-44%	148	-56%	159	-53%	75	-78%
UK	2839	1186	-58%	1181	-58%	1181	-58%	521	-82%
EU-15	13226	6849	-48%	6648	-50%	6054	-54%	2836	-79%
Albania	24	36	50%	36	50%	36	50%	6	-74%
Belarus	402	316	-21%	255	-37%	290	-28%	56	-86%
Bosnia-H	80	60	-25%	60	-25%	53	-34%	11	-86%
Bulgaria	355	297	-16%	266	-25%	266	-25%	61	-83%
Croatia	82	91	11%	87	6%	87	6%	16	-81%
Czech Rep.	546	296	-46%	286	-48%	188	-66%	78	-86%
Estonia	84	73	-13%	73	-13%	73	-13%	13	-85%
Hungary	219	198	-10%	198	-10%	137	-37%	50	-77%
Latvia	117	118	1%	84	-28%	118	1%	23	-81%
Lithuania	153	138	-10%	110	-28%	134	-12%	25	-83%
Norway	220	178	-19%	156	-29%	142	-35%	49	-78%
Poland	1217	879	-28%	879	-28%	654	-46%	266	-78%
R.of Moldova	87	66	-24%	90	3%	64	-26%	14	-84%
Romania	518	458	-12%	437	-16%	328	-37%	100	-81%
Russia	3486	2653	-24%	2653	-24%	2653	-24%	527	-85%
Slovakia	219	132	-40%	130	-41%	115	-47%	42	-81%
Slovenia	60	36	-40%	45	-25%	34	-43%	8	-87%
Switzerland	163	79	-52%	79	-52%	76	-53%	41	-75%
FYR Macedonia	39	29	-26%	29	-26%	29	-26%	5	-86%
Ukraine	1888	1433	-24%	1222	-35%	1222	-35%	325	-83%
Yugoslavia	211	152	-28%	152	-28%	132	-37%	27	-87%
Non-EU	10170	7718	-24%	7327	-28%	6830	-33%	1744	-83%
Total	23396	14567	-38%	13975	-40%	12884	-45%	4580	-80%



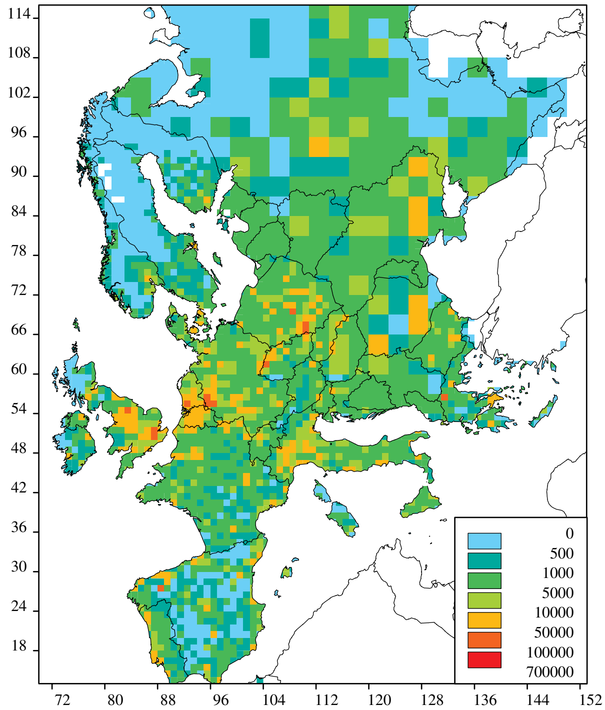
(a) 1990

(b) Protocol

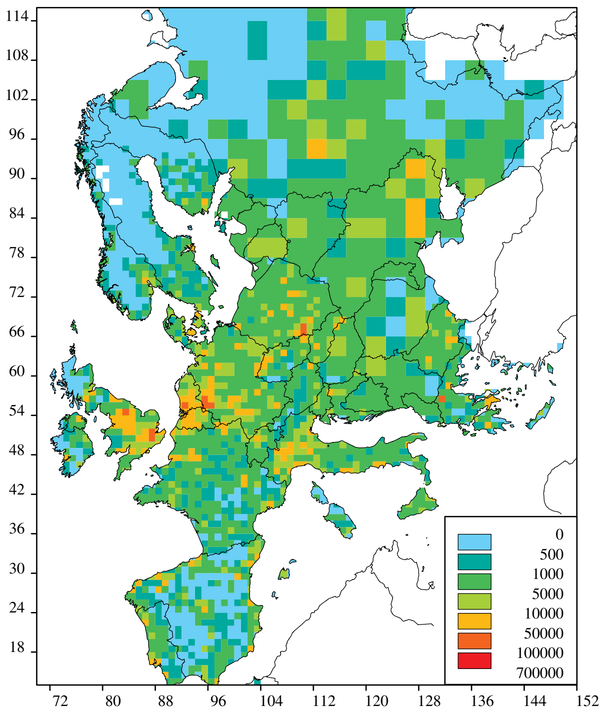
Figure 3.1: NO_x emission densities (tons per 50*50 km grid cell)



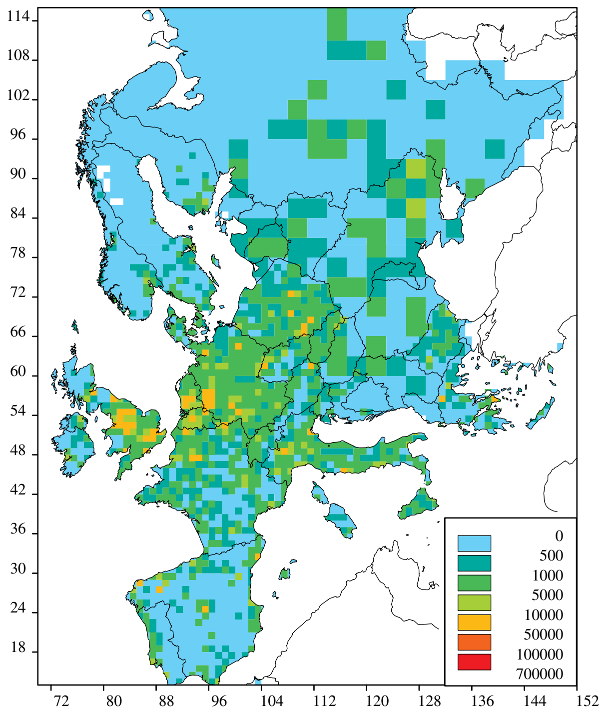
(a) REF scenario



(b) Protocol



(c) G5/2_{rev} scenario



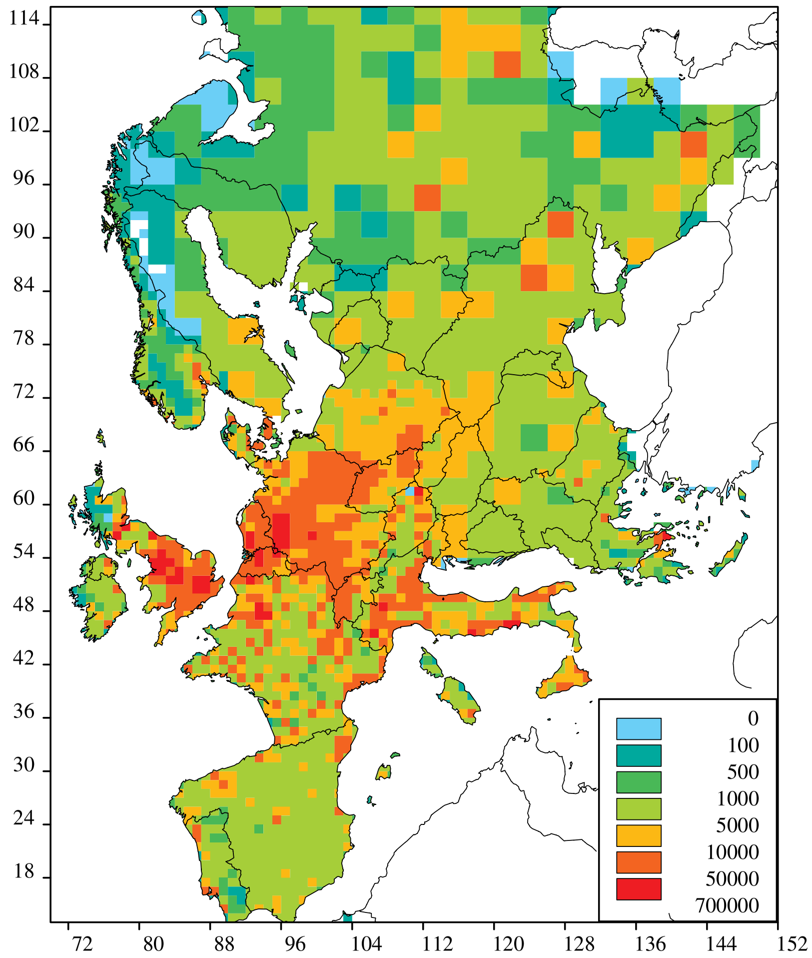
(d) MFR_{ult} scenario

Figure 3.2: NO_x emission densities (tons per 50*50 km grid cell)

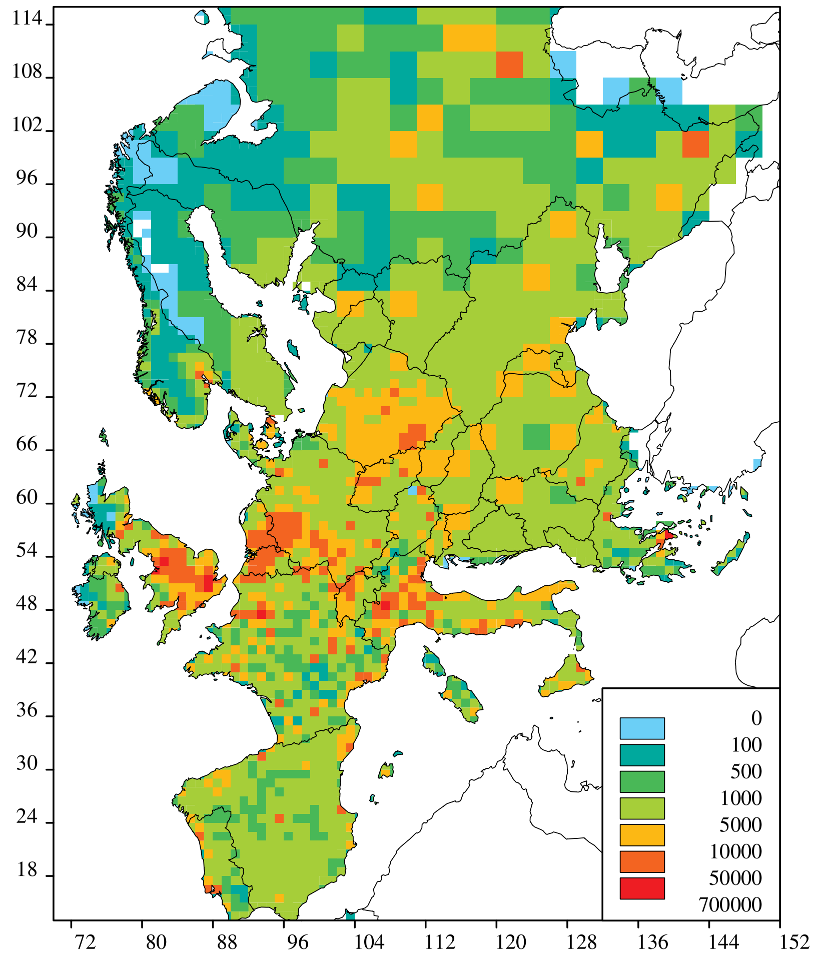
3.2 VOC Emissions

Table 3.2: Emissions of VOC for 1990 and the Reference (REF), Protocol, revised G5/2 and hypothetical maximum technically feasible reductions (MFR_{ult}) scenarios (in kilotons). Percentage changes relate to the year 1990.

	1990	REF		Protocol		G5/2rev		MFR_{ult}	
	kt	kt	Change	kt	Change	kt	Change	kt	Change
Austria	352	205	*-42%*	159	*-55%*	142	*-60%*	97	*-72%*
Belgium	374	193	*-48%*	144	*-61%*	103	*-72%*	85	*-77%*
Denmark	182	85	*-53%*	85	*-53%*	85	*-53%*	49	*-73%*
Finland	213	110	*-48%*	130	*-39%*	110	*-48%*	49	*-77%*
France	2382	1223	*-49%*	1100	*-54%*	989	*-58%*	658	*-73%*
Germany	3122	1137	*-64%*	995	*-68%*	995	*-68%*	644	*-79%*
Greece	336	267	*-21%*	261	*-22%*	261	*-22%*	100	*-70%*
Ireland	110	55	*-50%*	55	*-50%*	55	*-50%*	30	*-73%*
Italy	2055	1159	*-44%*	1159	*-44%*	1030	*-50%*	617	*-70%*
Luxembourg	19	7	*-63%*	9	*-53%*	7	*-63%*	5	*-76%*
Netherlands	490	233	*-52%*	191	*-61%*	157	*-68%*	136	*-72%*
Portugal	212	144	*-32%*	202	*-5%*	102	*-52%*	68	*-68%*
Spain	1008	669	*-34%*	669	*-34%*	648	*-36%*	365	*-64%*
Sweden	511	290	*-43%*	241	*-53%*	241	*-53%*	128	*-74%*
UK	2667	1351	*-49%*	1200	*-55%*	1101	*-59%*	841	*-68%*
EU-15	14031	7128	*-49%*	6600	*-53%*	6024	*-57%*	3872	*-72%*
Albania	31	41	*32%*	41	*32%*	41	*32%*	9	*-72%*
Belarus	371	309	*-17%*	309	*-17%*	298	*-20%*	71	*-81%*
Bosnia-H	51	48	*-6%*	48	*-6%*	48	*-6%*	11	*-79%*
Bulgaria	195	190	*-3%*	185	*-5%*	185	*-5%*	37	*-81%*
Croatia	103	111	*8%*	90	*-13%*	86	*-17%*	25	*-76%*
Czech Rep.	442	305	*-31%*	220	*-50%*	156	*-65%*	102	*-77%*
Estonia	45	49	*9%*	49	*9%*	49	*9%*	9	*-80%*
Hungary	204	160	*-22%*	137	*-33%*	137	*-33%*	50	*-75%*
Latvia	63	56	*-11%*	136	*116%*	56	*-11%*	11	*-82%*
Lithuania	111	105	*-5%*	92	*-17%*	105	*-5%*	33	*-70%*
Norway	297	195	*-34%*	195	*-34%*	195	*-34%*	124	*-58%*
Poland	797	807	*1%*	800	*0%*	475	*-40%*	284	*-64%*
R.of Moldova	50	42	*-16%*	100	*100%*	42	*-16%*	10	*-80%*
Romania	503	504	*0%*	523	*4%*	500	*-1%*	126	*-75%*
Russia	3542	2787	*-21%*	2786	*-21%*	2723	*-23%*	644	*-82%*
Slovakia	151	140	*-7%*	140	*-7%*	140	*-7%*	57	*-62%*
Slovenia	55	40	*-27%*	40	*-27%*	40	*-27%*	12	*-78%*
Switzerland	278	144	*-48%*	144	*-48%*	144	*-48%*	72	*-74%*
FYR Macedonia	19	19	*0%*	19	*0%*	19	*0%*	4	*-79%*
Ukraine	1161	851	*-27%*	797	*-31%*	770	*-34%*	165	*-86%*
Yugoslavia	142	139	*-2%*	139	*-2%*	138	*-3%*	26	*-82%*
Non-EU	8609	7041	*-18%*	6990	*-19%*	6345	*-26%*	1883	*-78%*
Total	22640	14168	*-37%*	13590	*-40%*	12370	*-45%*	5755	*-75%*

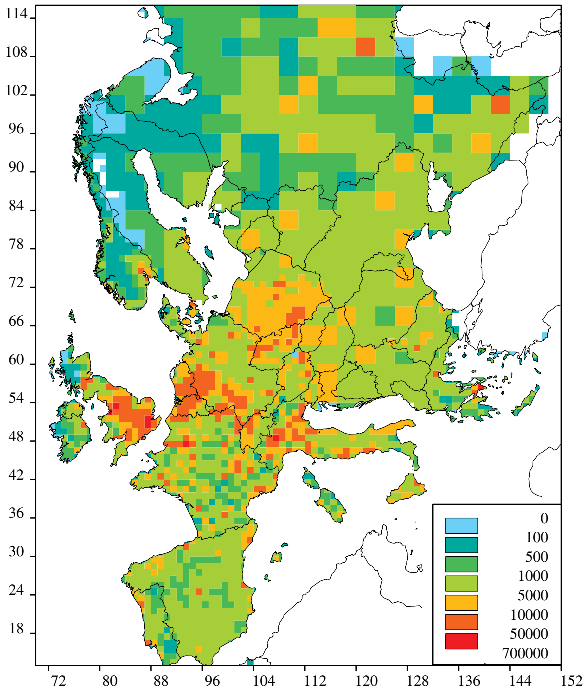


(a) 1990

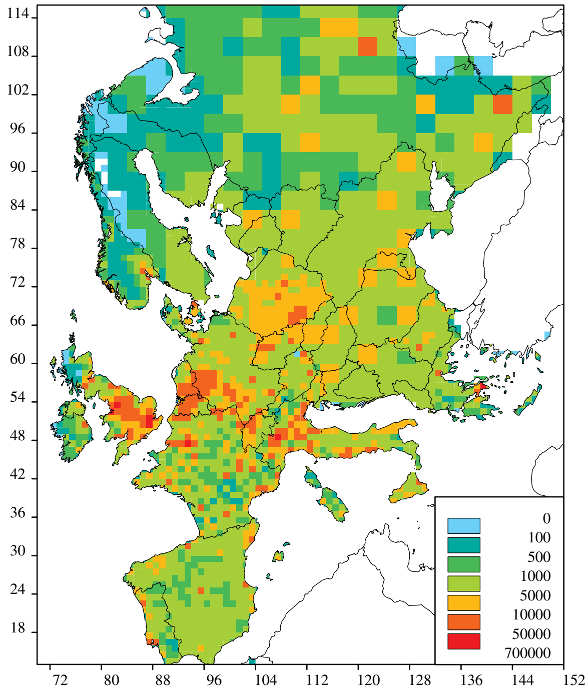


(b) Protocol

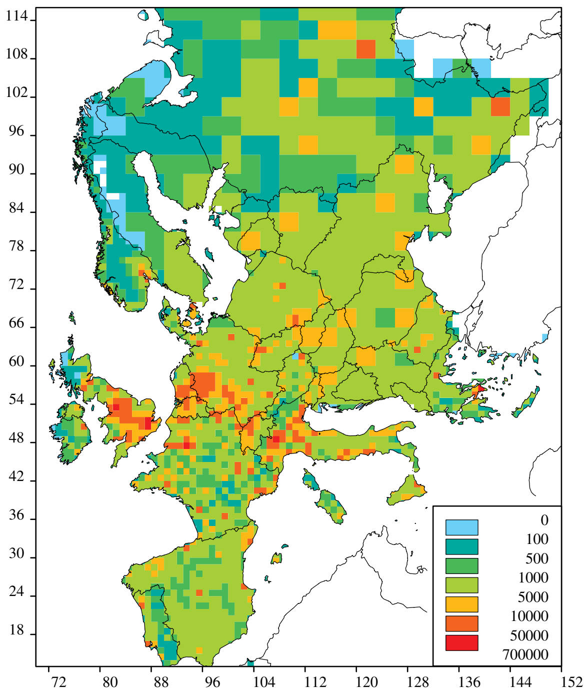
Figure 3.3: VOC emission densities (tons per 50*50 km grid cell)



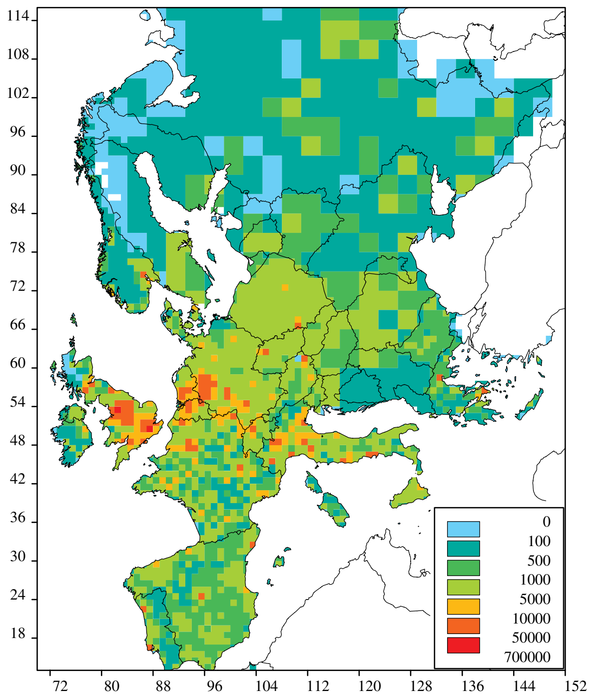
(a) REF scenario



(b) Protocol



(c) G5/2$_{rev}$ scenario



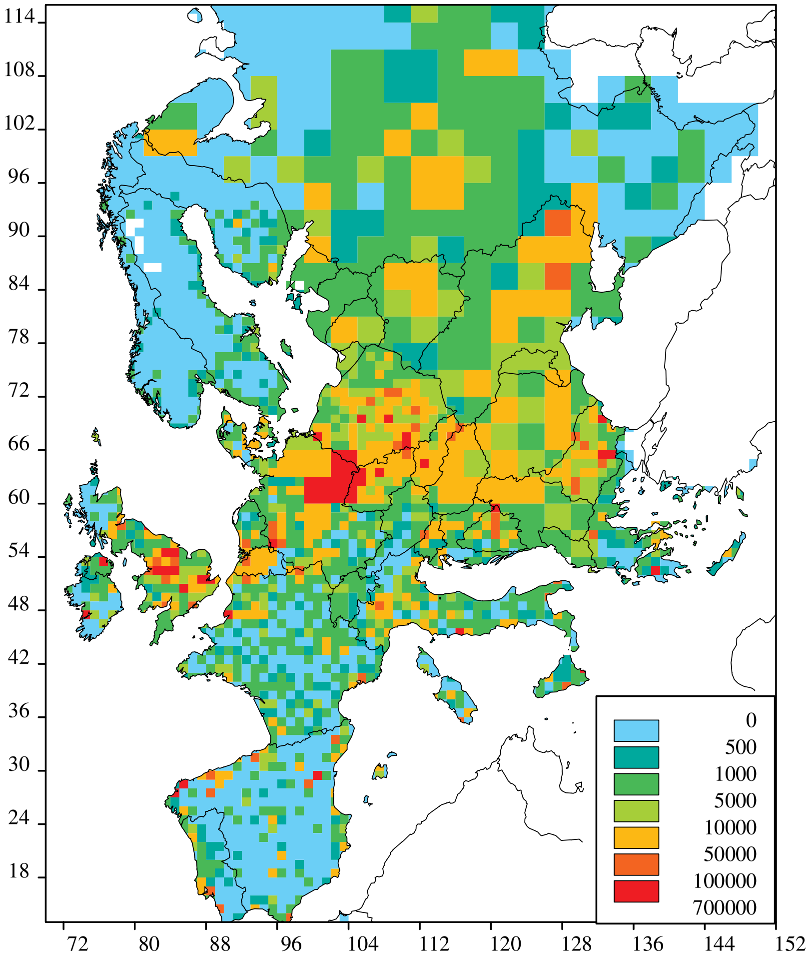
(d) MFR$_{ult}$ scenario

Figure 3.4: VOC emission densities (tons per 50*50 km grid cell)

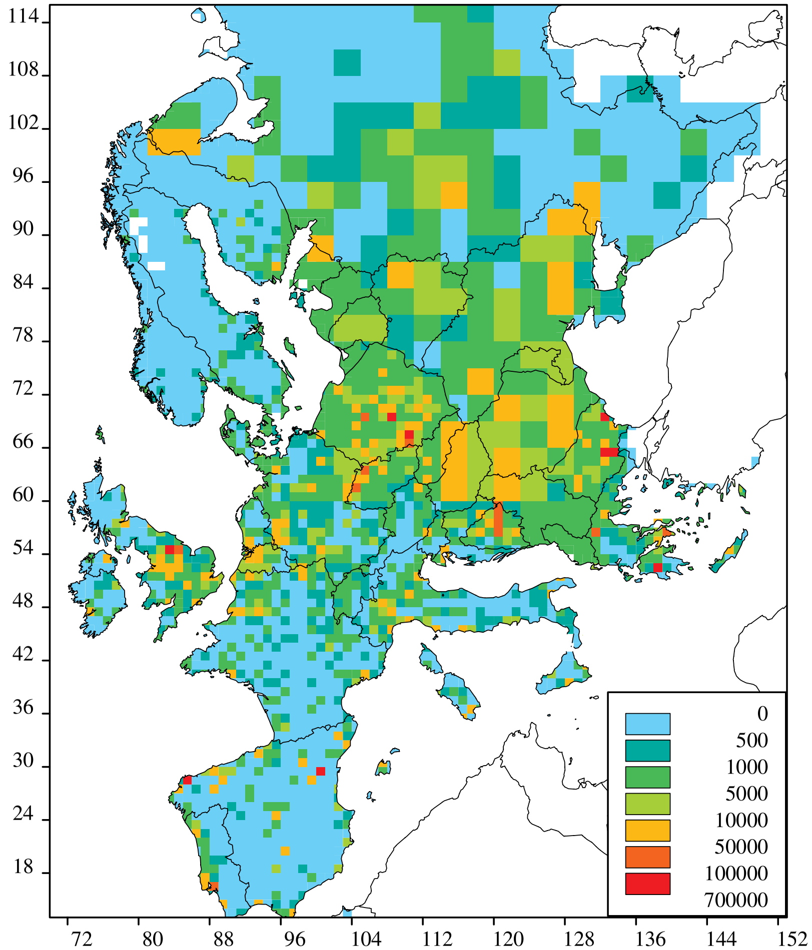
3.3 SO_2 Emissions

Table 3.3: Emissions of SO_2 for 1990 and the Reference (REF), Protocol, revised G5/2 and hypothetical maximum technically feasible reductions (MFR_{ult}) scenarios (in kilotons). Percentage changes relate to the year 1990.

	1990	REF		Protocol		G5/2rev		MFR_{ult}	
	kt	kt	Change	kt	Change	kt	Change	kt	Change
Austria	93	40	*-57%*	39	*-58%*	35	*-62%*	29	*-68%*
Belgium	336	193	*-43%*	106	*-68%*	76	*-77%*	60	*-82%*
Denmark	182	90	*-51%*	55	*-70%*	60	*-67%*	18	*-90%*
Finland	226	116	*-49%*	116	*-49%*	116	*-49%*	67	*-71%*
France	1250	448	*-64%*	400	*-68%*	219	*-82%*	162	*-87%*
Germany	5280	581	*-89%*	550	*-90%*	463	*-91%*	309	*-94%*
Greece	504	546	*8%*	546	*8%*	546	*8%*	86	*-83%*
Ireland	178	66	*-63%*	42	*-76%*	36	*-80%*	20	*-88%*
Italy	1679	567	*-66%*	500	*-70%*	290	*-83%*	190	*-89%*
Luxembourg	14	4	*-71%*	4	*-71%*	3	*-79%*	2	*-83%*
Netherlands	201	73	*-64%*	50	*-75%*	50	*-75%*	46	*-77%*
Portugal	284	141	*-50%*	170	*-40%*	141	*-50%*	28	*-90%*
Spain	2189	774	*-65%*	774	*-65%*	747	*-66%*	164	*-93%*
Sweden	119	67	*-44%*	67	*-44%*	67	*-44%*	51	*-57%*
UK	3805	980	*-74%*	625	*-84%*	499	*-87%*	284	*-93%*
EU-15	16339	4687	*-71%*	4044	*-75%*	3349	*-80%*	1516	*-91%*
Albania	72	55	*-24%*	55	*-24%*	55	*-24%*	6	*-91%*
Belarus	843	494	*-41%*	480	*-43%*	494	*-41%*	48	*-94%*
Bosnia-H	487	415	*-15%*	415	*-15%*	162	*-67%*	23	*-95%*
Bulgaria	1842	846	*-54%*	856	*-54%*	378	*-79%*	130	*-93%*
Croatia	180	70	*-61%*	70	*-61%*	23	*-87%*	16	*-91%*
Czech Rep.	1873	366	*-80%*	283	*-85%*	283	*-85%*	100	*-95%*
Estonia	275	175	*-36%*	175	*-36%*	175	*-36%*	13	*-95%*
Hungary	913	546	*-40%*	550	*-40%*	296	*-68%*	286	*-69%*
Latvia	121	104	*-14%*	107	*-12%*	104	*-14%*	17	*-86%*
Lithuania	213	107	*-50%*	145	*-32%*	107	*-50%*	22	*-90%*
Norway	52	32	*-38%*	22	*-58%*	18	*-65%*	17	*-68%*
Poland	3001	1397	*-53%*	1397	*-53%*	722	*-76%*	365	*-88%*
R.of Moldova	197	117	*-41%*	135	*-31%*	38	*-81%*	19	*-90%*
Romania	1331	594	*-55%*	918	*-31%*	148	*-89%*	92	*-93%*
Russia	5012	2344	*-53%*	2352	*-53%*	2186	*-56%*	533	*-89%*
Slovakia	548	137	*-75%*	110	*-80%*	92	*-83%*	68	*-88%*
Slovenia	200	71	*-65%*	27	*-87%*	14	*-93%*	10	*-95%*
Switzerland	43	26	*-40%*	26	*-40%*	23	*-47%*	12	*-73%*
FYR Macedonia	107	81	*-24%*	81	*-24%*	81	*-24%*	5	*-95%*
Ukraine	3706	1488	*-60%*	1457	*-61%*	1457	*-61%*	366	*-90%*
Yugoslavia	585	269	*-54%*	269	*-54%*	217	*-63%*	28	*-95%*
Non-EU	21599	9732	*-55%*	9930	*-54%*	7071	*-67%*	2178	*-90%*
Total	37938	14419	*-62%*	13974	*-63%*	10420	*-73%*	3695	*-90%*

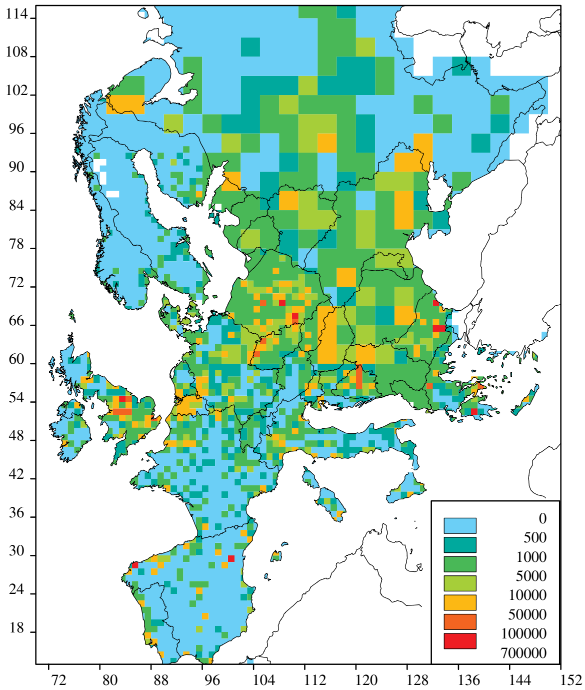


(a) 1990

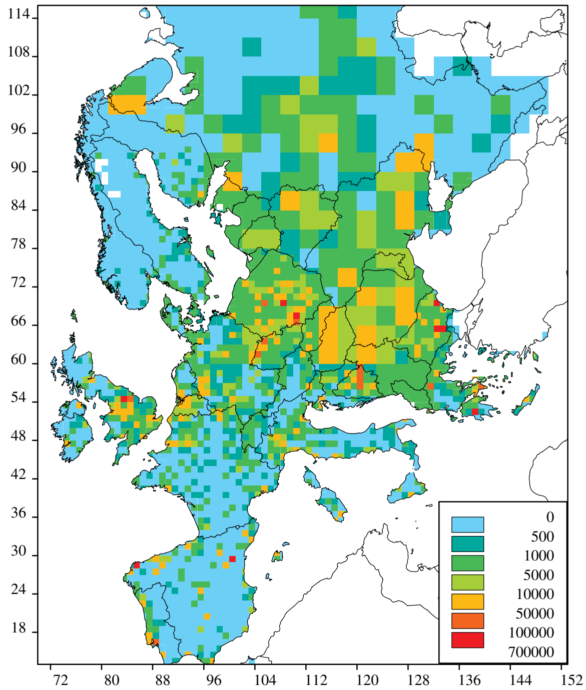


(b) Protocol

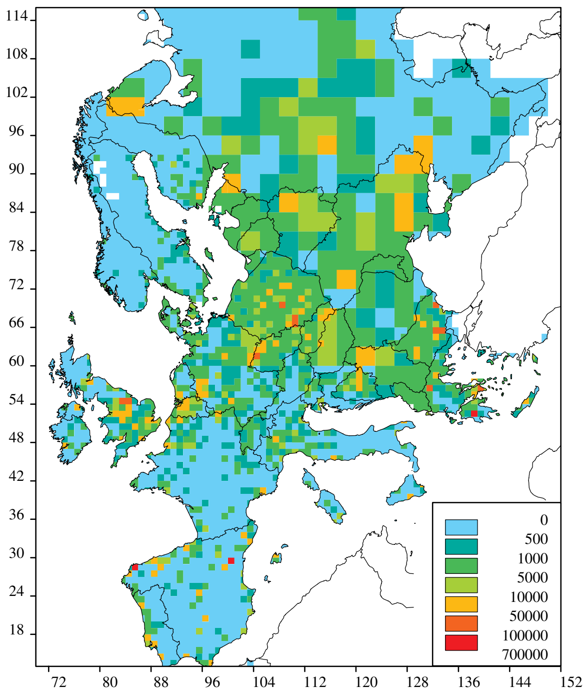
Figure 3.5: SO_2 emission densities (tons per 50*50 km grid cell)



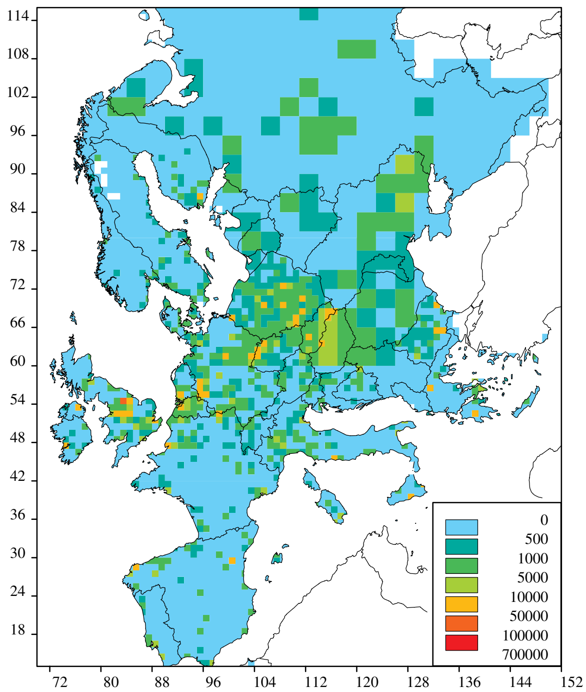
(a) REF scenario



(b) Protocol



(c) G5/2_{rev} scenario



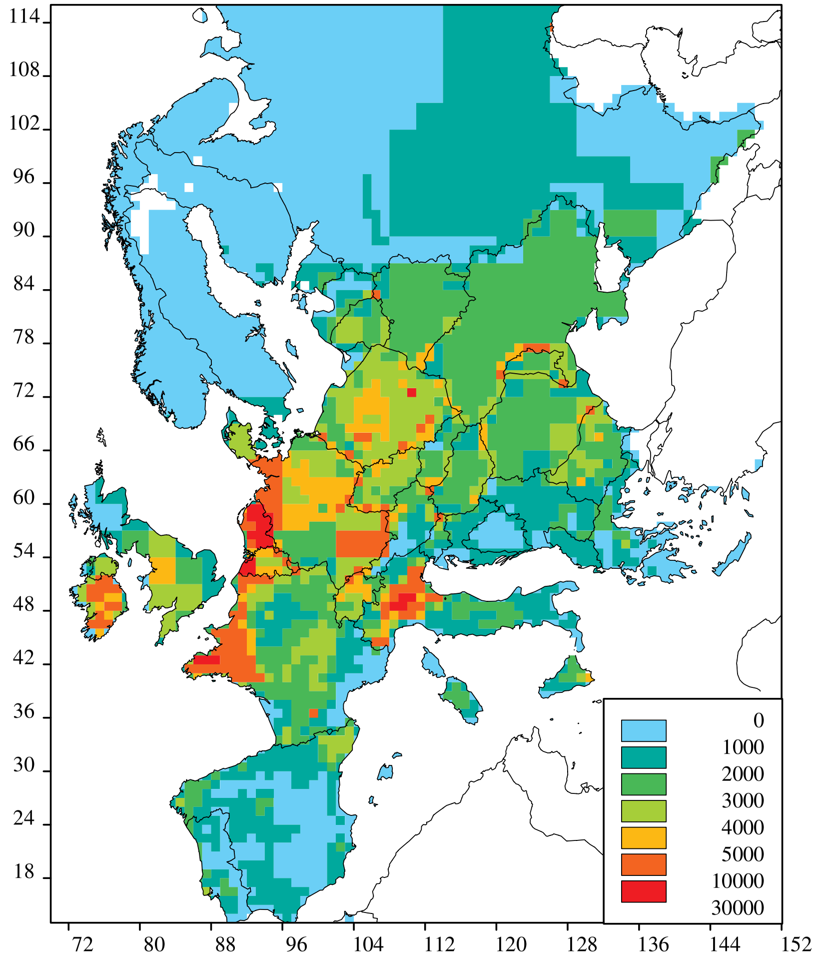
(d) MFR_{ult} scenario

Figure 3.6: SO_2 emission densities (tons per 50*50 km grid cell)

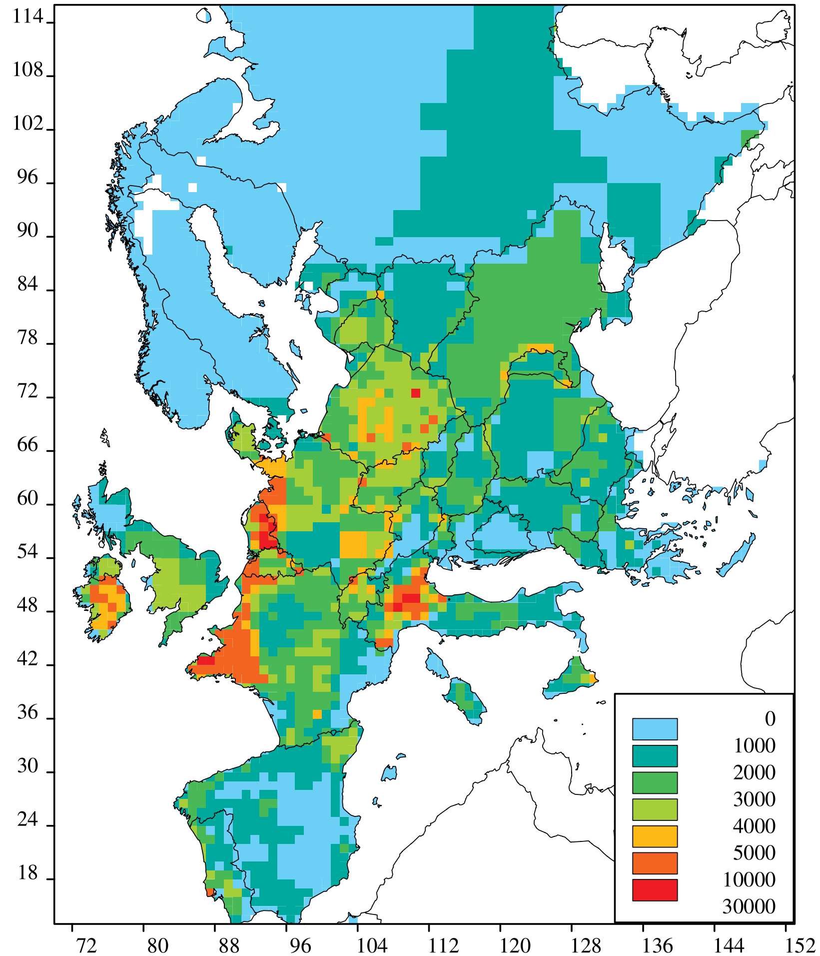
3.4 NH_3 Emissions

Table 3.4: Emissions of NH_3 for 1990 and the Reference (REF), Protocol, revised G5/2 and hypothetical maximum technically feasible reductions (MFR_{ult}) scenarios (in kilotons). Percentage changes relate to the year 1990.

	1990	REF		Protocol		G5/2rev		MFR_{ult}	
	kt	kt	Change	kt	Change	kt	Change	kt	Change
Austria	77	67	-13%	66	-14%	66	-14%	48	-38%
Belgium	97	96	-1%	74	-24%	60	-38%	57	-42%
Denmark	77	72	-6%	69	-10%	69	-10%	40	-47%
Finland	40	31	-23%	31	-23%	31	-23%	23	-43%
France	807	777	-4%	780	-3%	642	-20%	541	-33%
Germany	757	571	-25%	550	-27%	413	-45%	353	-53%
Greece	80	74	-8%	73	-9%	73	-9%	59	-26%
Ireland	127	126	-1%	116	-9%	116	-9%	111	-13%
Italy	462	432	-6%	419	-9%	356	-23%	282	-39%
Luxembourg	7	7	0%	7	0%	7	0%	7	-4%
Netherlands	233	136	-42%	128	-45%	105	-55%	105	-55%
Portugal	71	67	-6%	108	52%	65	-8%	46	-36%
Spain	352	353	0%	353	0%	353	0%	225	-36%
Sweden	61	48	-21%	57	-7%	48	-21%	44	-28%
UK	329	297	-10%	297	-10%	264	-20%	218	-34%
EU-15	3578	3154	-12%	3128	-13%	2668	-25%	2156	-40%
Albania	32	35	9%	35	9%	32	0%	25	-23%
Belarus	219	163	-26%	158	-28%	140	-36%	103	-53%
Bosnia-H	31	23	-26%	23	-26%	22	-29%	17	-45%
Bulgaria	141	126	-11%	108	-23%	105	-26%	86	-39%
Croatia	40	37	-8%	30	-25%	29	-28%	22	-46%
Czech Rep.	107	108	1%	101	-6%	101	-6%	72	-33%
Estonia	29	29	0%	29	0%	29	0%	16	-45%
Hungary	120	137	14%	90	-25%	77	-36%	73	-40%
Latvia	43	35	-19%	44	2%	35	-19%	19	-56%
Lithuania	80	81	1%	84	5%	72	-10%	49	-38%
Norway	23	21	-9%	23	0%	21	-9%	17	-27%
Poland	505	541	7%	468	-7%	468	-7%	367	-27%
R.of Moldova	47	48	2%	42	-11%	41	-13%	29	-39%
Romania	292	304	4%	210	-28%	227	-22%	206	-30%
Russia	1282	894	-30%	894	-30%	894	-30%	571	-55%
Slovakia	60	47	-22%	39	-35%	39	-35%	30	-50%
Slovenia	23	21	-9%	20	-13%	16	-30%	12	-49%
Switzerland	72	66	-8%	63	-13%	63	-13%	54	-25%
FYR Macedonia	17	16	-6%	16	-6%	15	-12%	11	-34%
Ukraine	729	649	-11%	592	-19%	588	-19%	406	-44%
Yugoslavia	90	82	-9%	82	-9%	64	-29%	54	-40%
Non-EU	3980	3462	-13%	3151	-21%	3077	-23%	2237	-44%
Total	7558	6616	-12%	6279	-17%	5745	-24%	4394	-42%

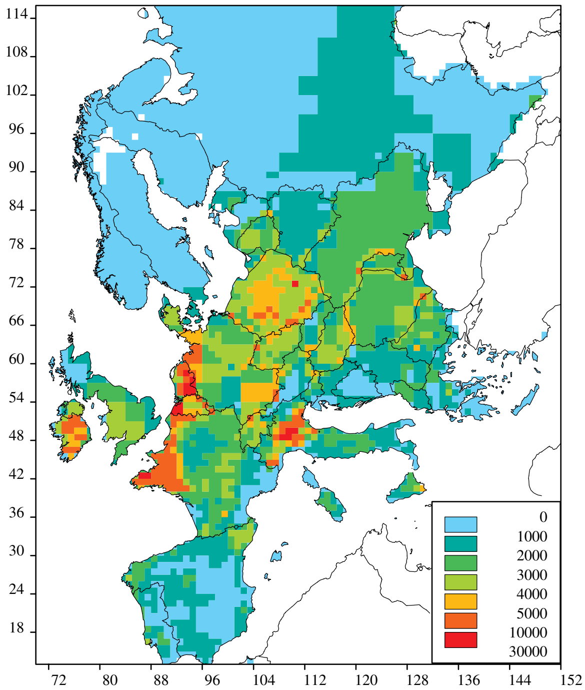


(a) 1990

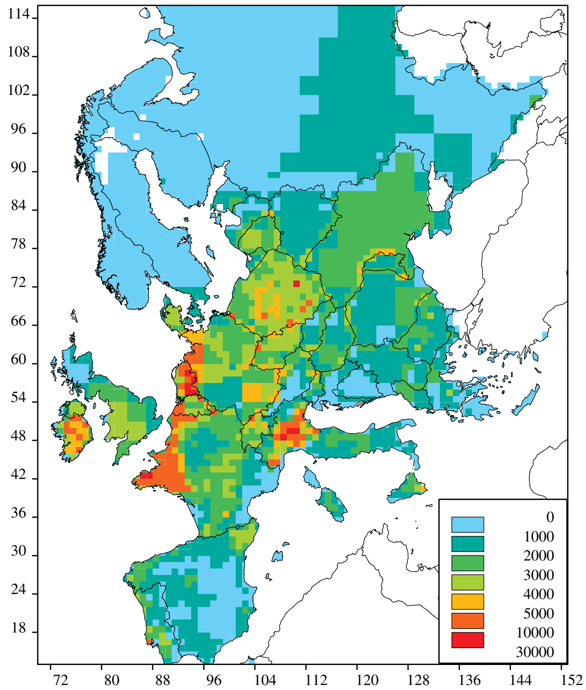


(b) Protocol

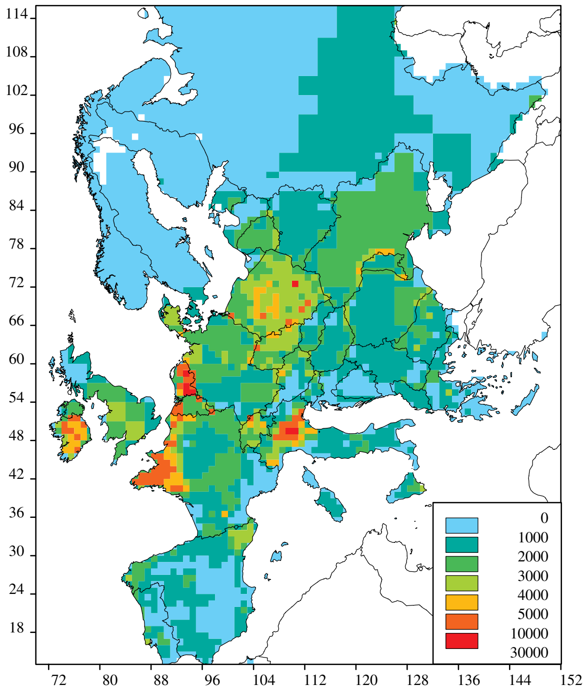
Figure 3.7: NH_3 emission densities (tons per 50*50 km grid cell)



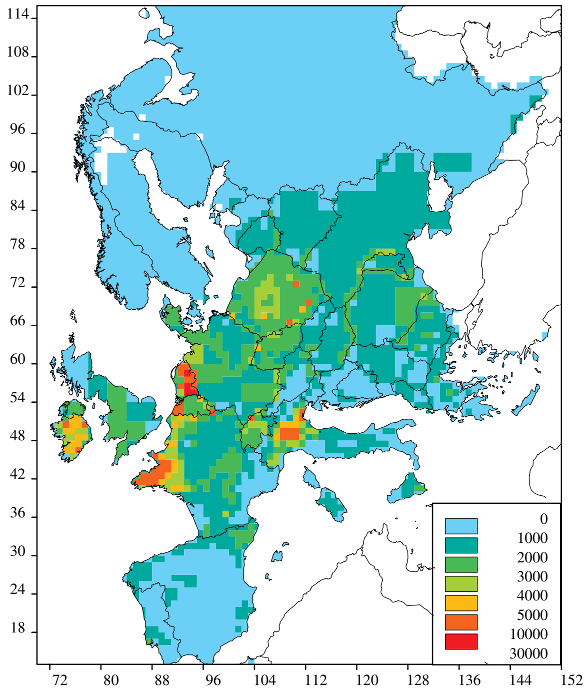
(a) REF scenario



(b) Protocol



(c) G5/2$_{rev}$ scenario



(d) MFR$_{ult}$ scenario

Figure 3.8: NH_3 emission densities (tons per 50*50 km grid cell)

3.5 Control Costs

Table 3.5: Costs of NO_x and VOC reductions for the Reference (REF), Protocol, revised G5/2 and hypothetical maximum technically feasible reductions (MFR_{ult}) scenarios (in million EURO/year).

	REF	Protocol		G5/2rev		MFR_{ult}
		Above REF	Total	Above REF	Total	Total
Austria	902	19†	921	70	972	1496
Belgium	1278	51	1329	452	1730	2101
Denmark	484	0	484	8	492	808
Finland	642	-5†	637	0	642	1026
France	7383	69†	7452	437	7820	11734
Germany	10549	484	11033	484	11033	15258
Greece	1048	2	1050	2	1050	2220
Ireland	477	0	477	10	487	716
Italy	7868	48	7916	245	8113	12482
Luxembourg	71	0†	70	2	73	110
Netherlands	1731	50	1780	112	1843	2735
Portugal	1349	-14†	1335	57	1406	2226
Spain	5658	0	5658	42	5700	8798
Sweden	1125	76	1201	45	1170	1899
UK	6695	171	6866	353	7048	11063
EU-15	47258	951	48210	2318	49576	74672
Albania	0	0	0	0	0	165
Belarus	0	21	21	3	3	1071
Bosnia-H	1	0	1	2	3	222
Bulgaria	4	10	14	10	14	1100
Croatia	1	3	4	5	6	416
Czech Rep.	568	43	611	235	803	1821
Estonia	0	0	0	0	0	269
Hungary	420	7	427	112	532	1436
Latvia	0	49†	49	0	0	346
Lithuania	0	31	31	0	0	505
Norway	567	5	572	12	579	1063
Poland	2487	0	2487	373	2860	6974
R.of Moldova	0	0†	0	0	0	215
Romania	2	2	4	100	102	1826
Russia	21	0	21	0	21	10431
Slovakia	331	0	332	11	342	1011
Slovenia	93	0†	94	1	94	285
Switzerland	831	0	831	2	833	1270
FYR Macedonia	1	0	1	0	1	102
Ukraine	0	43	43	44	44	4587
Yugoslavia	3	0	3	6	9	600
Non-EU	5332	213	5545	917	6249	35715
Total	52590	1165	53755	3235	55825	110387

† The Protocol NO_x and/or VOC emissions exceed the highest emissions considered on the relevant cost curve(s). The costs shown may be overestimated in such a case.

Table 3.6: Costs of SO_2 reductions for the Reference (REF), Protocol, revised G5/2 and hypothetical maximum technically feasible reductions (MFR_{ult}) scenarios (in million EURO/year).

	REF	Protocol		G5/2rev		MFR_{ult}
		Above REF	Total	Above REF	Total	Total
Austria	191	1	192	5	196	213
Belgium	426	47	472	122	548	631
Denmark	138	17	156	13	151	276
Finland	247	0	247	0	247	399
France	1276	17	1293	132	1408	1653
Germany	3264	16	3280	240	3504	3761
Greece	434	0	434	0	434	826
Ireland	132	9	142	12	144	192
Italy	1776	17	1793	87	1863	2122
Luxembourg	13	0	13	0	13	16
Netherlands	340	19	359	19	359	360
Portugal	181	0†	181	0	181	290
Spain	809	0	809	9	818	1275
Sweden	316	0	316	0	316	434
UK	1269	142	1411	295	1564	2674
EU-15	10813	285	11098	935	11748	15122
Albania	0	0	0	0	0	45
Belarus	0	4	4	0	0	297
Bosnia-H	0	0	0	55	55	144
Bulgaria	153	0†	153	58	211	369
Croatia	52	0	52	18	70	103
Czech Rep.	411	36	447	36	447	587
Estonia	0	0	0	0	0	115
Hungary	166	0†	166	113	279	336
Latvia	0	0†	0	0	0	86
Lithuania	0	0†	0	0	0	90
Norway	56	5	61	10	66	72
Poland	855	0	855	283	1138	2118
R.of Moldova	0	0†	0	30	30	72
Romania	155	0†	155	137	292	430
Russia	694	0	694	54	748	1974
Slovakia	91	11	102	25	116	150
Slovenia	35	18	52	23	58	80
Switzerland	118	0	118	1	119	155
FYR Macedonia	0	0	0	0	0	71
Ukraine	328	8	336	8	336	1069
Yugoslavia	88	0	88	27	115	391
Non-EU	3202	81	3283	879	4081	8754
Total	14016	365	14381	1814	15830	23876

† The Protocol emissions exceed the highest emissions considered on the cost curve. The costs shown are the minimum possible from the cost curve used; these may be an overestimate in such a case.

Table 3.7: Costs of NH_3 reductions for the Reference (REF), Protocol, revised G5/2 and hypothetical maximum technically feasible reductions (MFR_{ult}) scenarios (in million EURO/year).

	REF	Protocol		G5/2rev		MFR_{ult}
		Above REF	Total	Above REF	Total	Total
Austria	0	1	1	1	1	362
Belgium	0	93	93	312	312	496
Denmark	0	2	2	2	2	693
Finland	0	0	0	0	0	143
France	0	0†	0	367	367	2217
Germany	0	15	15	842	842	1816
Greece	0	0	0	0	0	222
Ireland	9	146	155	146	155	464
Italy	0	9	9	85	85	683
Luxembourg	15	0	15	0	15	15
Netherlands	196	95	291	672	868	1072
Portugal	0	0†	0	2	2	374
Spain	28	0	28	0	28	2043
Sweden	113	-106	7	0	113	230
UK	0	0	0	23	23	770
EU-15	361	256	617	2450	2811	11600
Albania	0	0	0	1	1	60
Belarus	0	2	2	9	9	433
Bosnia-H	0	0	0	1	1	78
Bulgaria	0	7	7	13	13	295
Croatia	0	3	3	3	3	119
Czech Rep.	0	10	10	9	9	411
Estonia	0	0	0	0	0	88
Hungary	0	107	107	319	319	493
Latvia	0	0†	0	0	0	113
Lithuania	0	0†	0	4	4	246
Norway	0	0†	0	3	3	108
Poland	0	182	182	182	182	1527
R.of Moldova	0	2	2	3	3	127
Romania	0	615	615	304	304	834
Russia	0	0	0	0	0	2943
Slovakia	0	8	8	7	7	173
Slovenia	0	0	0	2	2	64
Switzerland	0	5	5	6	6	187
FYR Macedonia	0	0	0	1	1	43
Ukraine	0	24	24	30	30	2126
Yugoslavia	0	0	0	94	94	346
Non-EU	0	967	967	991	991	10813
Total	361	1223	1584	3442	3803	22413

† The Protocol emissions exceed the highest emissions considered on the cost curve. The costs shown are the minimum possible from the cost curve used; these may be an overestimate in such a case.

Table 3.8: Total costs (all pollutants) for the Reference (REF), Protocol, revised G5/2 and hypothetical maximum technically feasible reductions (MFR_{ult}) scenarios (in million EURO/year).

	REF	Protocol		G5/2rev		MFR_{ult}
		Above REF	Total	Above REF	Total	Total
Austria	1093	20	1113	76	1169	2071
Belgium	1704	191	1895	886	2590	3228
Denmark	623	19	642	22	645	1777
Finland	889	-5	884	0	889	1568
France	8659	86	8745	936	9595	15604
Germany	13813	516	14329	1567	15380	20835
Greece	1482	2	1484	2	1484	3268
Ireland	618	155	774	168	786	1372
Italy	9644	74	9718	417	10061	15287
Luxembourg	98	0	98	2	100	141
Netherlands	2267	164	2431	803	3070	4167
Portugal	1530	-14	1516	59	1589	2890
Spain	6495	0	6495	51	6546	12116
Sweden	1554	-29	1524	45	1599	2563
UK	7964	313	8277	671	8635	14507
EU-15	58433	1492	59925	5704	64137	101394
Albania	0	0	0	1	1	270
Belarus	0	26	26	12	12	1801
Bosnia-H	1	0	1	58	59	444
Bulgaria	157	17	174	81	238	1764
Croatia	52	6	59	26	78	638
Czech Rep.	979	89	1068	280	1259	2819
Estonia	0	0	0	0	0	472
Hungary	586	113	700	545	1131	2265
Latvia	0	49	49	0	0	545
Lithuania	0	31	31	4	4	841
Norway	623	10	633	25	648	1243
Poland	3342	182	3524	838	4180	10619
R.of Moldova	0	2	2	33	33	414
Romania	157	617	774	541	698	3090
Russia	715	0	715	54	769	15348
Slovakia	423	19	442	43	466	1334
Slovenia	128	18	146	25	153	429
Switzerland	949	5	954	9	958	1612
FYR Macedonia	1	0	1	1	2	216
Ukraine	328	75	403	82	410	7782
Yugoslavia	92	0	92	128	220	1337
Non-EU	8534	1261	9795	2787	11321	55282
Total	66967	2753	69720	8490	75457	156676

4 ENVIRONMENTAL IMPACTS

4.1 Acidification

The comparison between the scenarios in terms of their impacts on acidification are presented in this report using the following indicators:

- Maps of acid deposition are shown in Figure 4.1 - Figure 4.2.
- The area and percentage of ecosystems with acid deposition above their critical loads are tabulated in Table 4.1. A second series of maps (Figure 4.3 - Figure 4.4) shows the percentage of ‘unprotected’ ecosystems across Europe.
- Table 4.2 provides the total accumulated excess load by country for the four scenarios.
- A further series of maps (Figure 4.5 - Figure 4.6) shows the excess acid deposition over the 2-percentile critical load.

Figure 4.3(a) displays the percentage of ecosystems for which, for the emissions of 1990, acid deposition is calculated to exceed the critical loads. Least protection occurred in a band ranging from northern France through Germany to the Czech Republic and Poland. Overall, critical loads were exceeded in about 93 million hectares of ecosystems, of which 37 million hectares were located in the EU-15 (see Table 4.1).

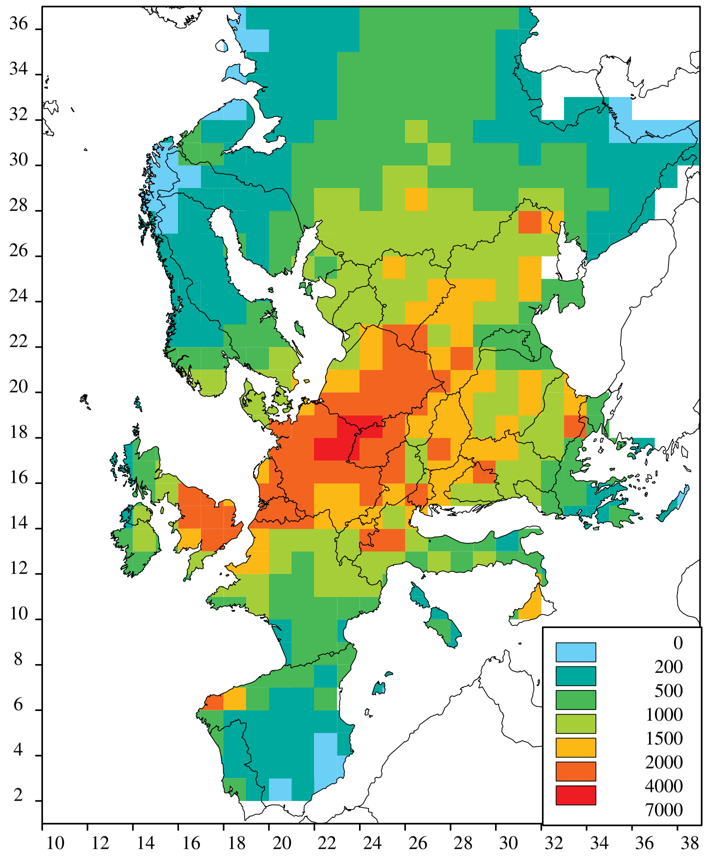
The emission reductions anticipated in the REF scenario are expected to improve the situation significantly (Figure 4.4(a)) and to decrease the unprotected ecosystems to about 17.5 million hectares, out of which 6.4 million hectares are located in the EU-15. There is clear indication that the overall area where critical loads are exceeded will decline, and many areas where the situation was not extreme will achieve full protection. On the other hand, there are some regions (northern Germany, southern Norway, northern Sweden, Hungary, Kola) where the improvement will not exceed 10 to 30 percent.

Further improvements are expected with the revised G5/2 scenario (Figure 4.4(c)) and MFR_{ult} scenario (Figure 4.4(d)), which reduce the total European area of unprotected ecosystems to about 8 million hectares and 2 million hectares, respectively. The Protocol emissions are expected to leave 15 million hectares unprotected.

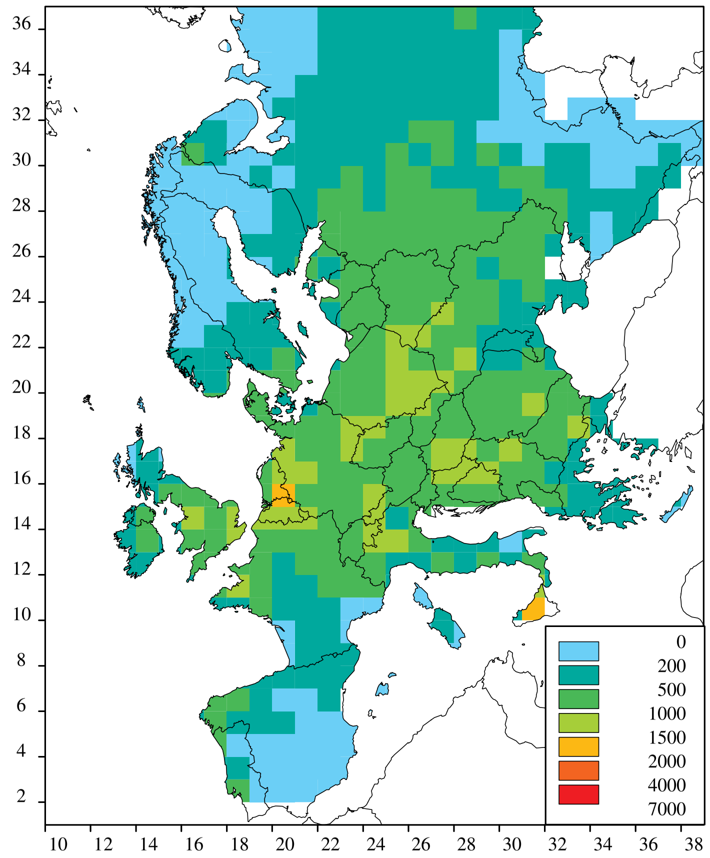
The 'accumulated excess' concept offers a continuous measure for excess acid deposition. The total accumulated excess load is calculated as the product of the excess deposition and the area of ecosystems affected by the excess, integrated over all areas with excess deposition. Both the total excess load and the average accumulated excess by country for the four scenarios are given in Table 4.2. This table shows that the Protocol is calculated to reduce total European excess load by 96 percent, while the revised G5/2 scenario targeted a 98 percent reduction compared to 1990.

Another way of evaluating the ecological situation from a given emission pattern is to examine for a given percentile of the ecosystems the remaining excess deposition. For the five scenarios presented here, Figure 4.5 - Figure 4.6 display this information for the 2-percentile, i.e., for the ecosystem where two percent of the ecosystems in the same grid cell have lower critical loads and 98 percent of the ecosystems in the grid cell have higher critical loads. The map for the revised G5/2 scenario (Figure 4.6(c)) clearly indicates that, despite the significant emission reductions, there remain ecosystems where acid deposition is 500 to 1000 eq/ha above their critical loads, i.e., where the critical loads are exceeded by a factor of two and more. Such high levels of excess deposition would occur on the German/Dutch border, in southern UK and on the Swiss/Italian border.

4.1.1 Acid Deposition

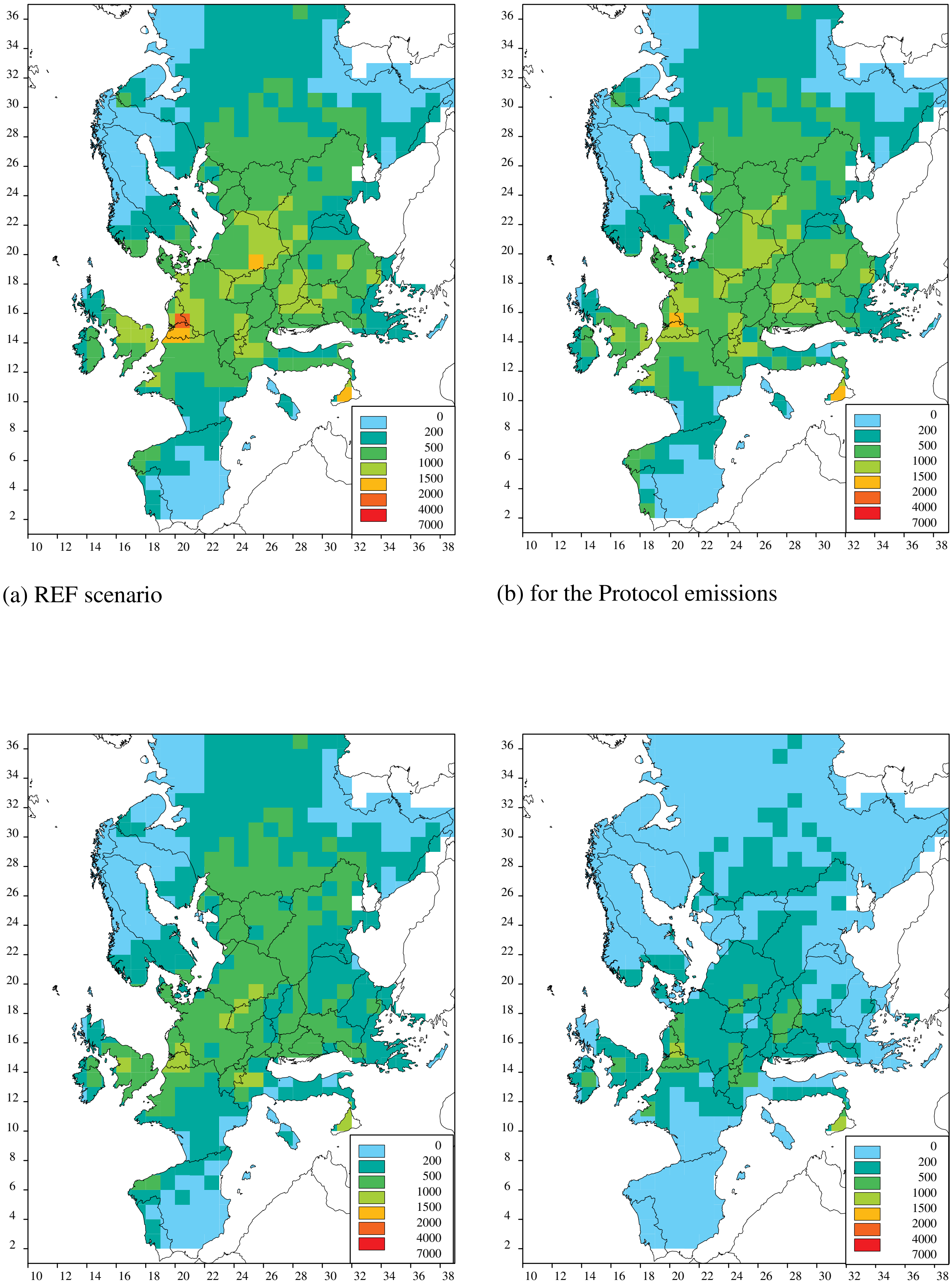


(a) for the emissions of 1990



(b) for the Protocol emissions

Figure 4.1: (Potential) acid deposition (equivalents/ha/year)



(a) REF scenario

(b) for the Protocol emissions

(c) G5/2_{rev} scenario

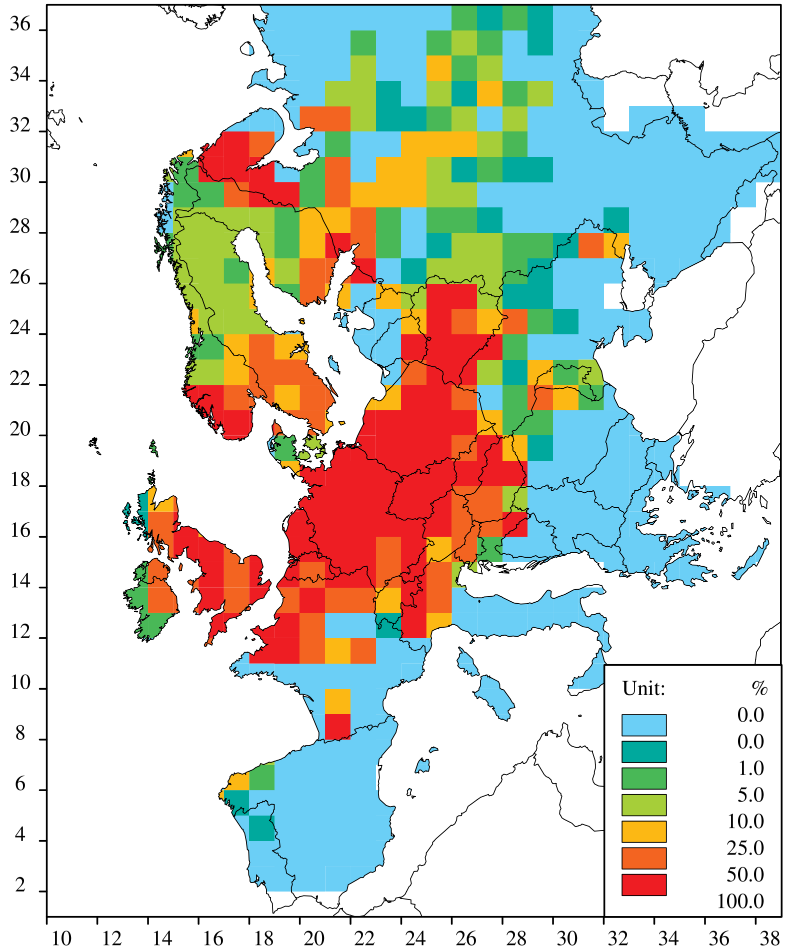
(d) MFR_{ult} scenario

Figure 4.2: (Potential) acid deposition (equivalents/ha/year)

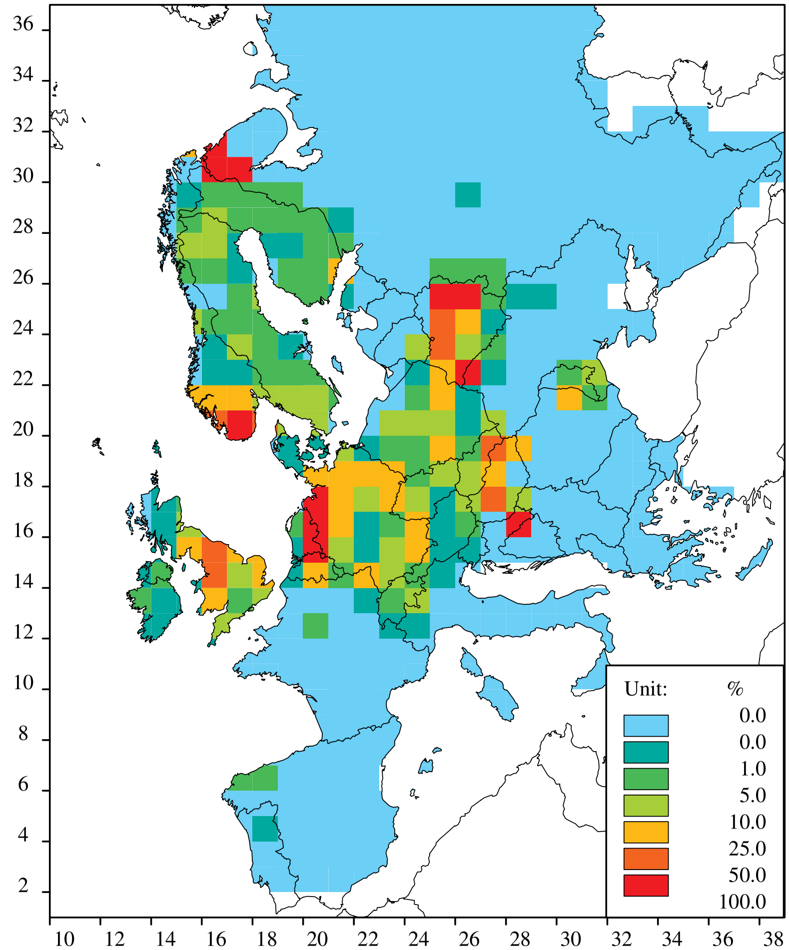
4.1.2 Ecosystems Protection

Table 4.1: Ecosystems with acid deposition above their critical loads for acidification for 1990 and the Reference (REF), Protocol, revised G5/2 and hypothetical maximum technically feasible reductions (MFR_{ult}) scenarios.

	1000 hectares					Percent of ecosystems				
	1990	REF	Protocol	G5/2rev	MFR_{ult}	1990	REF	Protocol	G5/2rev	MFR_{ult}
Austria	2376	162	127	68	35	47.6	3.3	2.5	1.4	0.7
Belgium	410	155	110	52	7	58.4	22.1	15.6	7.4	0.9
Denmark	54	9	7	5	1	13.8	2.3	1.9	1.2	0.4
Finland	4725	1183	1163	756	152	17.3	4.3	4.3	2.8	0.6
France	8191	218	116	84	4	25.8	0.7	0.4	0.3	0.0
Germany	8158	1617	1209	567	119	79.5	15.8	11.8	5.5	1.2
Greece	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
Ireland	97	12	9	8	6	10.7	1.3	1.0	0.9	0.7
Italy	2065	74	61	51	43	19.6	0.7	0.6	0.5	0.4
Luxembourg	58	5	4	1	0	66.7	5.9	4.8	0.8	0.1
Netherlands	285	193	160	76	30	89.3	60.4	50.1	23.7	9.5
Portugal	1	1	1	1	0	0.0	0.0	0.0	0.0	0.0
Spain	78	17	18	17	0	0.9	0.2	0.2	0.2	0.0
Sweden	6348	1605	1465	1166	457	16.4	4.1	3.8	3.0	1.2
UK	4117	1182	882	636	65	43.0	12.3	9.2	6.6	0.7
EU-15	36963	6433	5332	3486	919	24.7	4.3	3.6	2.3	0.6
Albania	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
Belarus	2709	1048	1005	686	0	53.9	20.9	20.0	13.6	0.0
Bosnia-H	132	131	131	0	0	9.1	9.1	9.0	0.0	0.0
Bulgaria	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
Croatia	7	0	0	0	0	2.7	0.0	0.0	0.0	0.0
Czech Rep.	2394	474	224	81	12	90.1	17.9	8.4	3.0	0.5
Estonia	314	11	10	8	0	16.6	0.6	0.5	0.4	0.0
Hungary	144	65	47	37	10	50.7	22.9	16.4	13.0	3.6
Latvia	128	0	0	0	0	4.7	0.0	0.0	0.0	0.0
Lithuania	817	78	79	5	0	43.1	4.1	4.2	0.3	0.0
Norway	5314	2573	2340	1928	771	24.0	11.6	10.6	8.7	3.5
Poland	12634	1357	953	173	14	72.8	7.8	5.5	1.0	0.1
R.of Moldova	84	29	30	10	0	7.1	2.4	2.5	0.9	0.0
Romania	231	51	53	17	6	3.7	0.8	0.8	0.3	0.1
Russia	27105	4073	4108	1026	31	7.9	1.2	1.2	0.3	0.0
Slovakia	1033	295	240	149	110	51.5	14.7	11.9	7.4	5.5
Slovenia	363	19	5	4	3	40.1	2.1	0.6	0.4	0.3
Switzerland	508	57	48	35	26	41.1	4.6	3.9	2.8	2.1
FYR of Maced.	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
Ukraine	2397	643	554	237	5	29.1	7.8	6.7	2.9	0.1
Yugoslavia	2	2	2	0	0	0.1	0.1	0.1	0.0	0.0
Non-EU	56315	10908	9829	4397	989	13.1	2.5	2.3	1.0	0.2
Total	93278	17341	15161	7883	1909	16.1	3.0	2.6	1.4	0.3

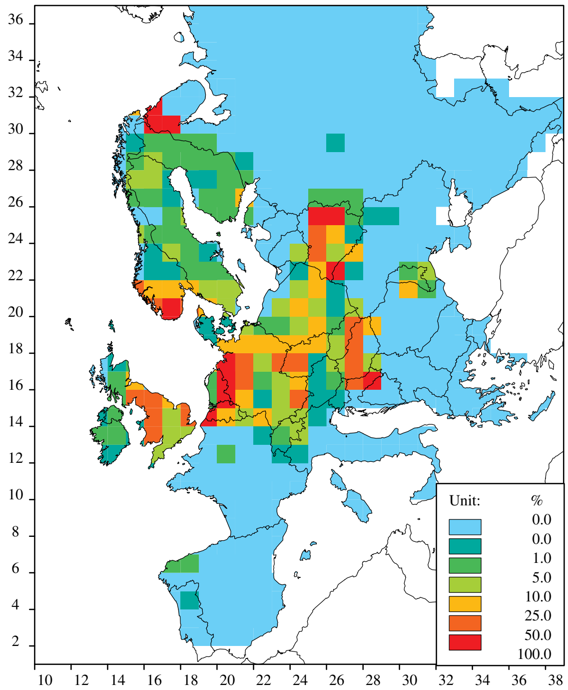


(a) for the emissions of 1990

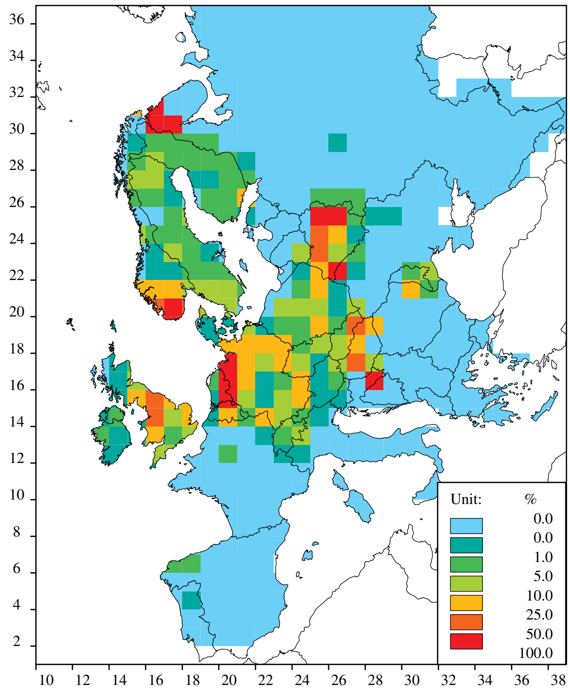


(b) for the Protocol emissions

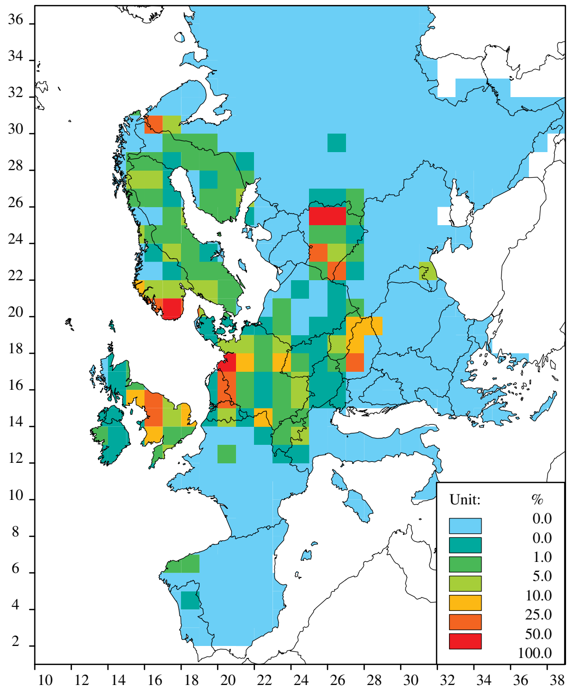
Figure 4.3: Percentage of ecosystems with acid deposition above the critical loads



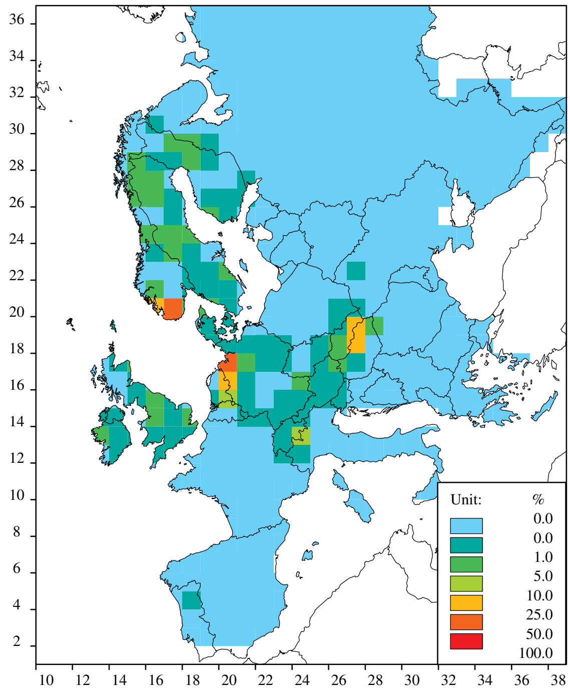
(a) REF scenario



(b) for the Protocol emissions



(c) G5/2$_{rev}$ scenario



(d) MFR$_{ult}$ scenario

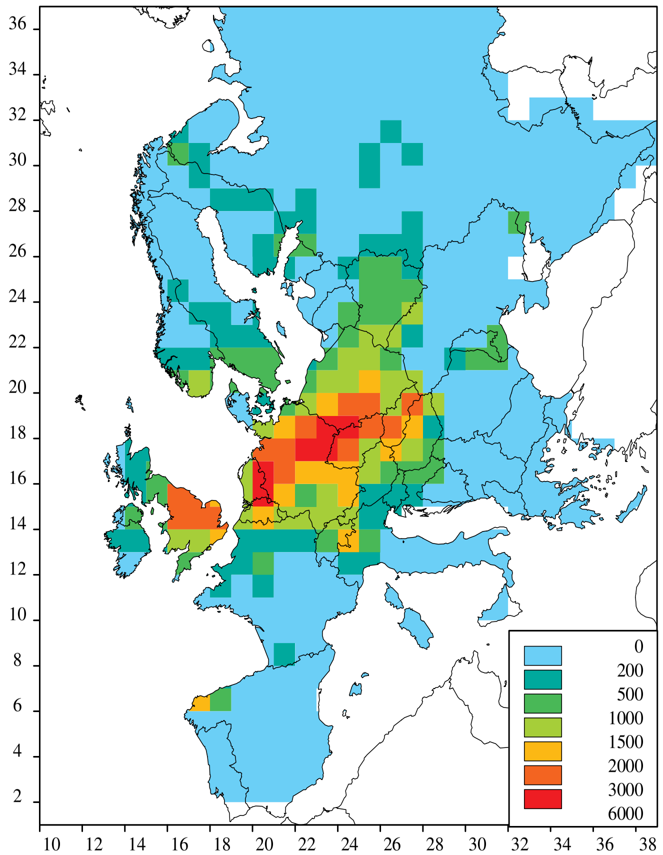
Figure 4.4: Percentage of ecosystems with acid deposition above the critical loads for acidification

4.1.3 Total Excess Load

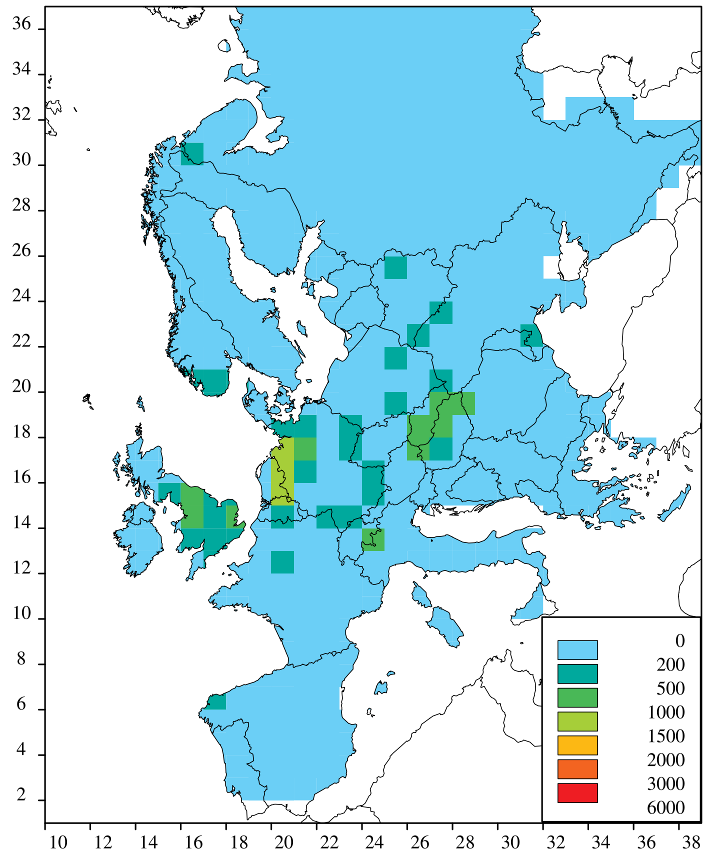
Table 4.2: Accumulated excess acid deposition above the critical loads for acidification for 1990 and the Reference (REF), Protocol, revised G5/2 and hypothetical maximum technically feasible reductions (MFR_{ult}) scenarios.

	Total (million equivalents/year)					Average (equivalents/ha/year)				
	1990	REF	Protocol	G5/2rev	MFR_{ult}	1990	REF	Protocol	G5/2rev	MFR_{ult}
Austria	1565	51	38	17	6	313.5	10.1	7.6	3.3	1.2
Belgium	464	77	41	11	2	660.3	110.0	57.9	15.1	2.8
Denmark	22	2	1	1	0	55.2	3.9	2.7	1.4	0.3
Finland	760	135	134	51	7	27.8	4.9	4.9	1.9	0.2
France	2003	44	28	10	1	63.1	1.4	0.9	0.3	0.0
Germany	12470	477	322	118	20	1215.6	46.5	31.4	11.5	1.9
Greece	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
Ireland	19	3	2	2	1	20.4	3.0	2.2	2.0	1.0
Italy	821	44	37	25	11	77.8	4.2	3.5	2.4	1.0
Luxembourg	24	1	1	0	0	278.7	13.1	8.1	0.8	0.1
Netherlands	583	115	73	29	8	1823.4	358.4	228.6	90.6	25.9
Portugal	0	0	0	0	0	0.1	0.1	0.1	0.1	0.0
Spain	51	4	4	3	0	5.9	0.4	0.4	0.4	0.0
Sweden	1590	148	123	82	21	41.0	3.8	3.2	2.1	0.6
UK	3510	335	186	100	6	366.4	35.0	19.4	10.4	0.7
EU-15	23881	1434	990	448	82	159.8	9.6	6.6	3.0	0.6
Albania	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
Belarus	1241	127	110	44	0	246.9	25.3	21.9	8.7	0.0
Bosnia-H	101	10	1	0	0	69.7	6.8	0.5	0.0	0.0
Bulgaria	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
Croatia	2	0	0	0	0	8.5	0.0	0.0	0.0	0.0
Czech Rep.	5005	83	37	12	2	1884.0	31.3	14.1	4.4	0.6
Estonia	50	1	1	1	0	26.5	0.5	0.5	0.3	0.0
Hungary	118	28	21	6	3	412.7	99.8	73.4	20.9	8.8
Latvia	4	0	0	0	0	1.5	0.0	0.0	0.0	0.0
Lithuania	305	5	7	0	0	161.0	2.5	3.7	0.0	0.0
Norway	2146	484	405	293	57	97.0	21.9	18.3	13.2	2.6
Poland	16933	258	154	32	2	976.1	14.9	8.9	1.8	0.1
R.of Moldova	25	5	7	1	0	21.0	4.2	5.6	1.1	0.0
Romania	70	16	17	3	1	11.2	2.5	2.8	0.5	0.1
Russia	3116	387	402	53	2	9.0	1.1	1.2	0.2	0.0
Slovakia	1017	134	105	43	24	507.0	66.9	52.1	21.2	12.1
Slovenia	71	3	1	1	0	78.4	3.0	1.3	0.8	0.4
Switzerland	279	26	23	14	6	226.1	21.4	18.4	11.7	4.8
FYR of Maced.	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
Ukraine	1235	124	88	20	1	149.9	15.1	10.7	2.4	0.1
Yugoslavia	2	0	0	0	0	0.5	0.1	0.0	0.0	0.0
Non-EU	31722	1692	1379	521	97	73.6	3.9	3.2	1.2	0.2
Total	55603	3126	2369	968	179	95.8	5.4	4.1	1.7	0.3

4.1.4 Excess Deposition over 2-Percentile Critical load

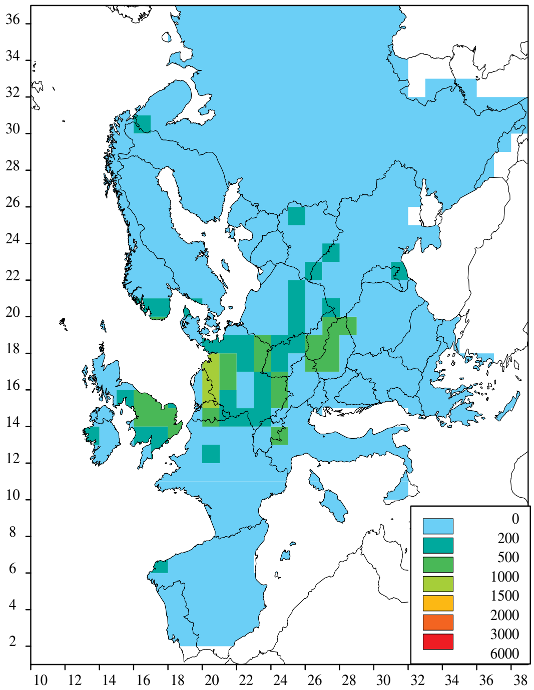


(a) for the emissions of 1990

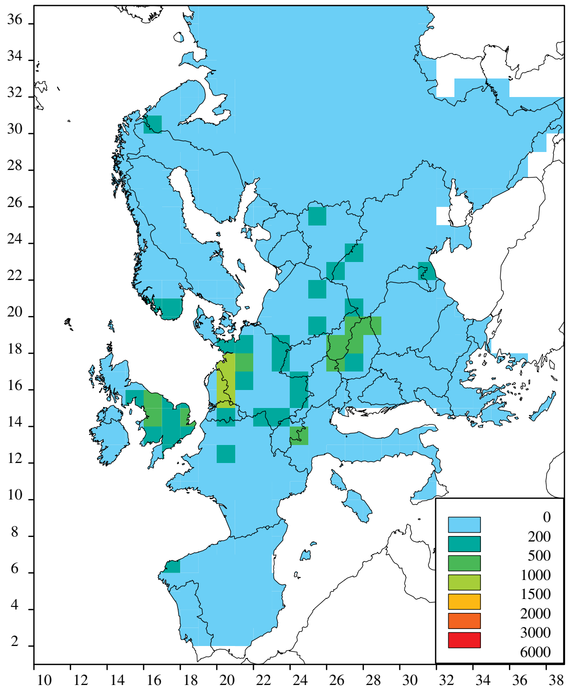


(b) for the Protocol emissions

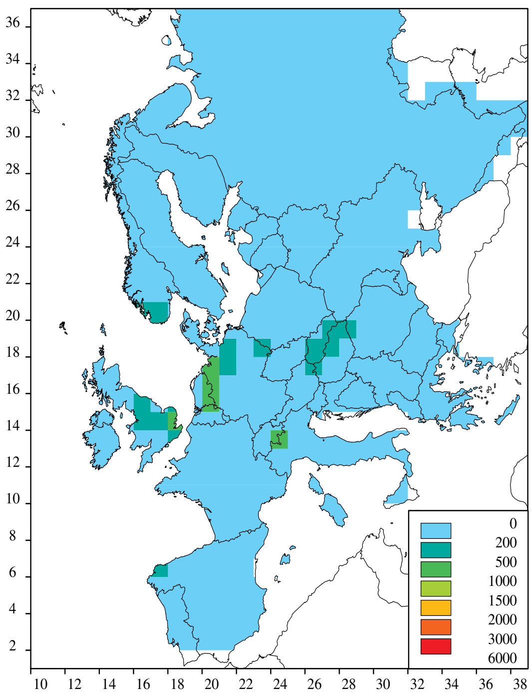
Figure 4.5: Excess deposition over the 2-percentile critical load (equivalents/ha/year)



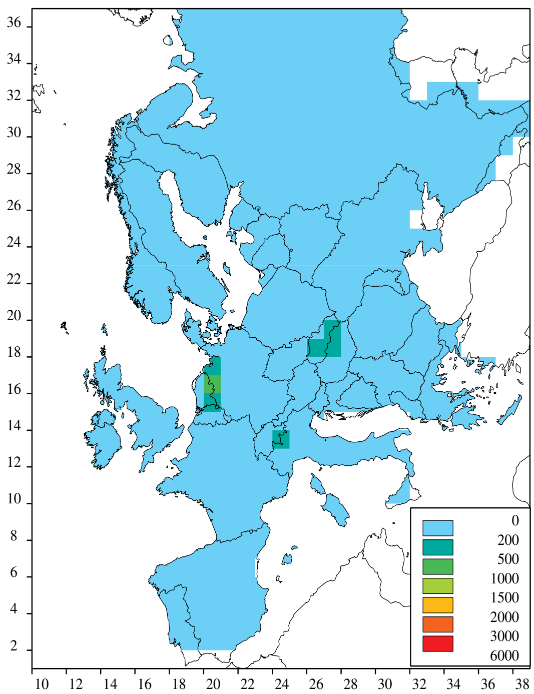
(a) REF scenario



(b) for the Protocol emissions



(c) $G5/2_{rev}$ scenario



(d) MFR_{ult} scenario

Figure 4.6: Excess deposition over the 2-percentile critical load (equivalents/ha/year)

4.2 Eutrophication

The comparison between the scenarios in terms of their impacts on eutrophication is presented here using the following indicators:

- Maps of nitrogen deposition are shown in Figure 4.7-Figure 4.8.
- The area and percentage of ecosystems with nitrogen deposition above their critical loads are given in Table 4.3. A second series of maps (Figure 4.9-Figure 4.10) shows the percentage of ‘unprotected’ ecosystems across Europe.
- Table 4.4 provides the total accumulated excess load by country for the four scenarios.
- A third series of maps (Figure 4.11-Figure 4.12) shows the excess nitrogen deposition over the 2-percentile critical load.

Figure 4.9(a) shows that in 1990 eutrophication was a widespread phenomenon in many parts of central Europe. The majority of grid cells in France, Germany, Poland, Ukraine and Bulgaria experienced excess deposition for all of their ecosystems. In Europe as a whole, critical loads for eutrophication were exceeded in more than 165 million hectares (Table 4.3).

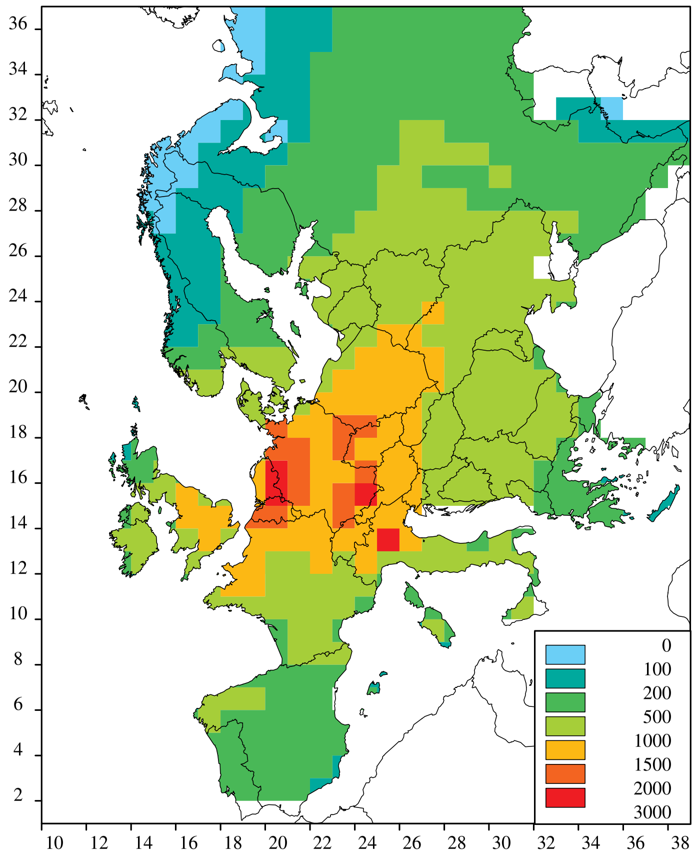
The emission reductions anticipated from the REF scenario will relieve the situation to some extent (Figure 4.10a), but will still leave 116 million hectares unprotected (Table 4.3). In many parts of mainland Europe they will not be sufficient to increase the unprotected ecosystems substantially. Statistics for individual countries are presented in Table 4.3.

Some moderate further improvement would be expected with the revised G5/2 scenario (Figure 4.10c), which reduces the total European area of ecosystems with nitrogen deposition above their critical loads for eutrophication to 94 million hectares. In fact, for the Protocol 108 million hectares are calculated to have deposition above the critical loads. The MFR_{ult} scenario (Figure 4.10d) is expected to reduce the unprotected area to 35 million hectares.

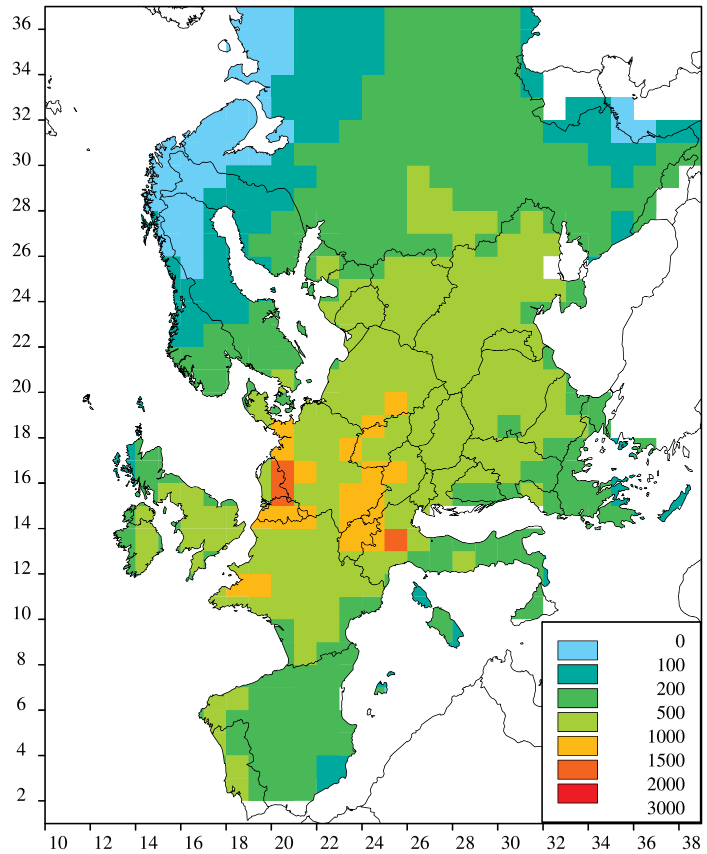
The 'accumulated excess' concept offers a continuous measure for excess deposition. The total accumulated excess load by country for the four scenarios is given in Table 4.4.

Figure 4.11-Figure 4.12 display the excess nitrogen deposition for the 'two percentile' ecosystems. Peak excess deposition occurs on the German/Dutch border and in northern Italy in all four scenarios.

4.2.1 Nitrogen Deposition

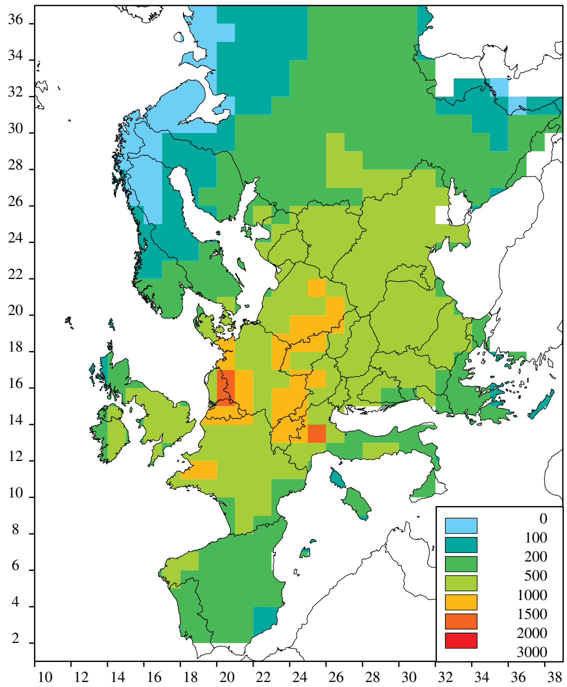


(a) for the emissions of 1990

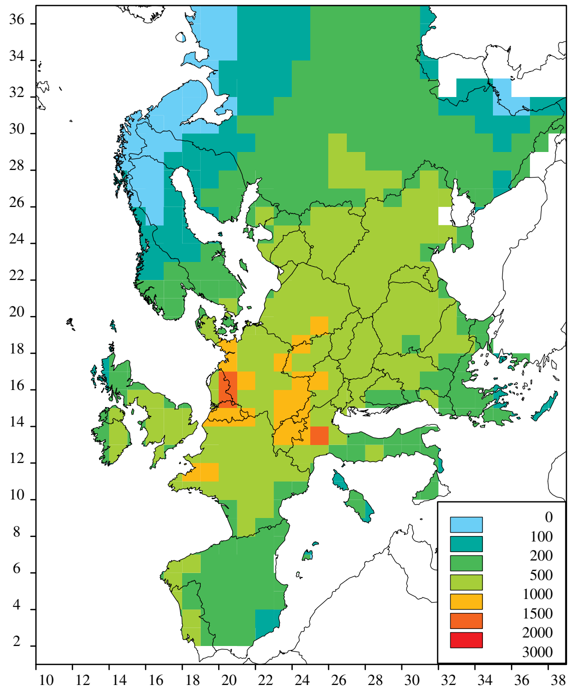


(b) for the Protocol emissions

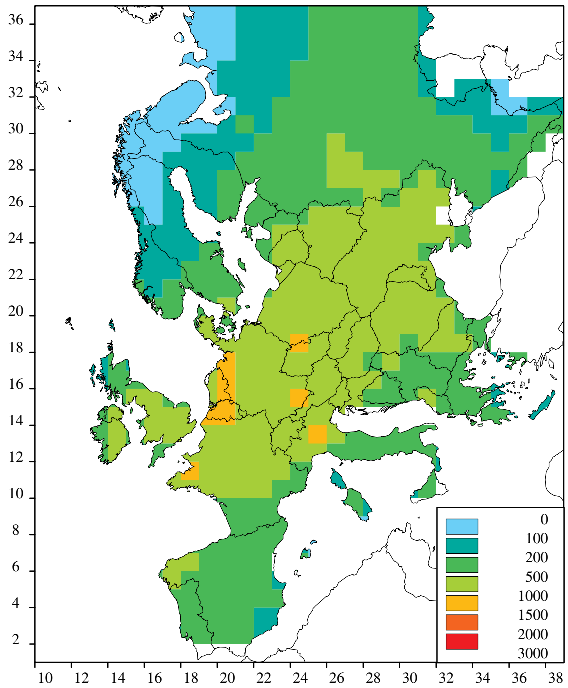
Figure 4.7: Total nitrogen deposition (equivalents/ha/year)



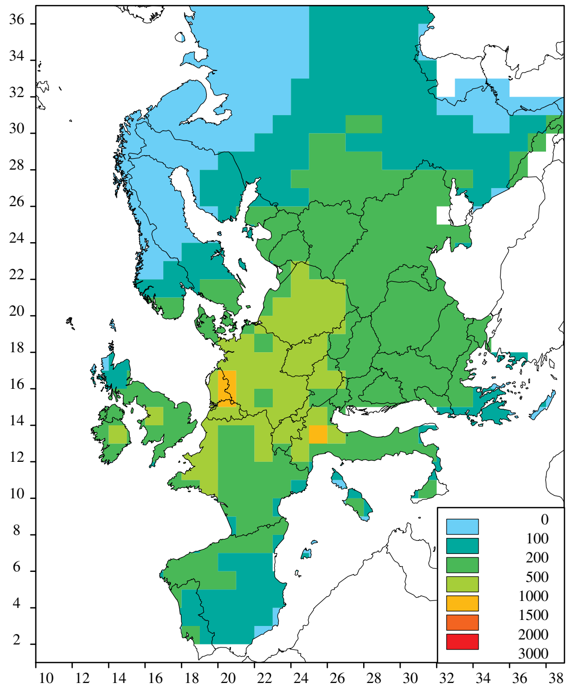
(a) REF scenario



(b) for the Protocol emissions



(c) G5/2_{rev} scenario



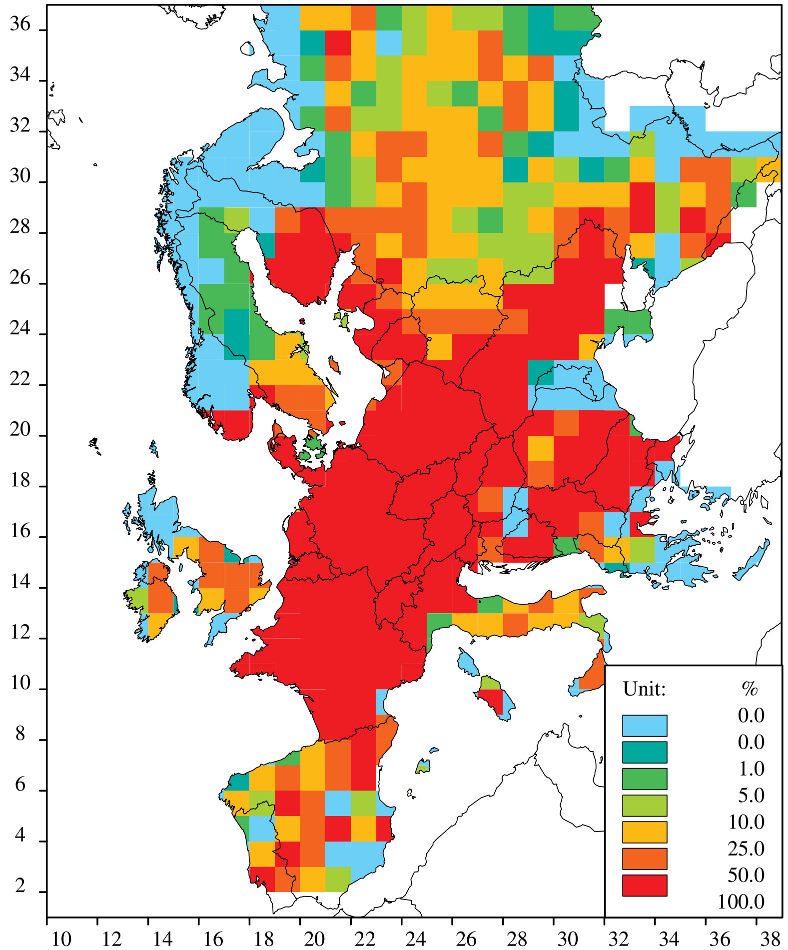
(d) MFR_{ult} scenario

Figure 4.8: Total nitrogen deposition (equivalents/ha/year)

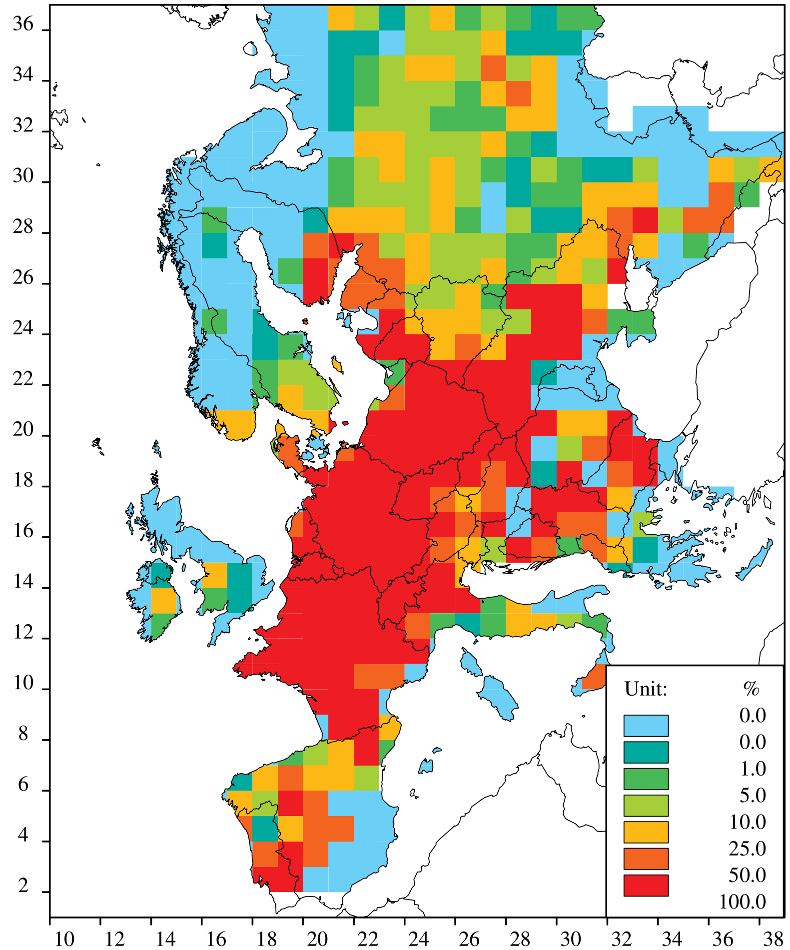
4.2.2 Ecosystems Protection

Table 4.3: Ecosystems with nitrogen deposition above their critical loads for eutrophication for 1990 and the Reference (REF), Protocol, revised G5/2 and hypothetical maximum technically feasible reductions (MFR_{ult}) scenarios.

	1000 hectares					Percent of ecosystems				
	1990	REF	Protocol	G5/2rev	MFR_{ult}	1990	REF	Protocol	G5/2rev	MFR_{ult}
Austria	5392	3441	3154	2477	572	90.3	57.6	52.8	41.5	9.6
Belgium	700	677	656	572	335	99.6	96.4	93.5	81.4	47.8
Denmark	197	119	99	85	4	62.7	37.6	31.5	26.9	1.3
Finland	7386	2538	2157	1738	10	44.8	15.4	13.1	10.5	0.1
France	29320	25160	24920	21632	13079	92.3	79.2	78.4	68.1	41.2
Germany	10157	9184	8887	7312	3590	99.0	89.5	86.6	71.3	35.0
Greece	295	236	106	85	8	12.0	9.6	4.3	3.5	0.3
Ireland	91	58	33	29	23	10.0	6.4	3.7	3.2	2.5
Italy	5921	3795	3591	2508	1382	49.4	31.7	30.0	20.9	11.5
Luxembourg	88	80	79	63	45	100.0	91.3	89.5	72.2	50.8
Netherlands	312	291	287	278	252	97.8	91.0	89.7	87.0	79.0
Portugal	913	709	1221	580	0	32.3	25.1	43.2	20.5	0.0
Spain	2390	1158	1463	850	8	28.0	13.6	17.2	10.0	0.1
Sweden	2588	891	863	620	64	13.8	4.7	4.6	3.3	0.3
UK	1030	126	124	62	0	11.2	1.4	1.3	0.7	0.0
EU-15	66778	48461	47639	38890	19372	55.3	40.2	39.5	32.2	16.1
Albania	240	200	192	160	60	22.6	18.8	18.0	15.1	5.7
Belarus	2049	1293	1075	924	370	40.8	25.7	21.4	18.4	7.4
Bosnia-H	1104	725	657	460	115	76.2	50.0	45.3	31.7	8.0
Bulgaria	3964	3396	2122	1263	123	80.1	68.7	42.9	25.5	2.5
Croatia	70	18	17	10	0	25.9	6.8	6.3	3.6	0.0
Czech Rep.	2608	2312	2235	1983	491	98.2	87.0	84.1	74.6	18.5
Estonia	1296	738	682	598	30	68.5	39.0	36.1	31.6	1.6
Hungary	166	150	132	125	85	58.2	52.8	46.5	44.1	29.8
Latvia	2260	1553	1554	1417	90	83.2	57.2	57.2	52.2	3.3
Lithuania	1462	1357	1345	894	74	77.1	71.6	70.9	47.2	3.9
Norway	2053	281	253	35	2	14.7	2.0	1.8	0.3	0.0
Poland	16875	16218	15505	14894	7726	97.3	93.5	89.4	85.9	44.5
R.of Moldova	1	0	0	0	0	0.1	0.0	0.0	0.0	0.0
Romania	3450	2495	1799	1770	1194	55.4	40.0	28.9	28.4	19.2
Russia	47704	26263	24006	23123	1254	13.8	7.6	7.0	6.7	0.4
Slovakia	1874	1507	1163	939	241	93.5	75.2	58.0	46.8	12.0
Slovenia	489	156	142	87	44	54.0	17.2	15.7	9.6	4.9
Switzerland	2105	1887	1762	1468	823	92.4	82.8	77.3	64.4	36.1
FYR of Maced.	242	158	136	108	45	22.7	14.9	12.7	10.1	4.2
Ukraine	6181	5331	4053	3859	1808	75.0	64.7	49.2	46.8	22.0
Yugoslavia	2306	1994	1895	1280	945	67.6	58.5	55.5	37.5	27.7
Non-EU	98498	68032	60726	55396	15520	23.2	16.0	14.3	13.1	3.7
Total	165276	116494	108365	94287	34892	30.3	21.4	19.9	17.3	6.4

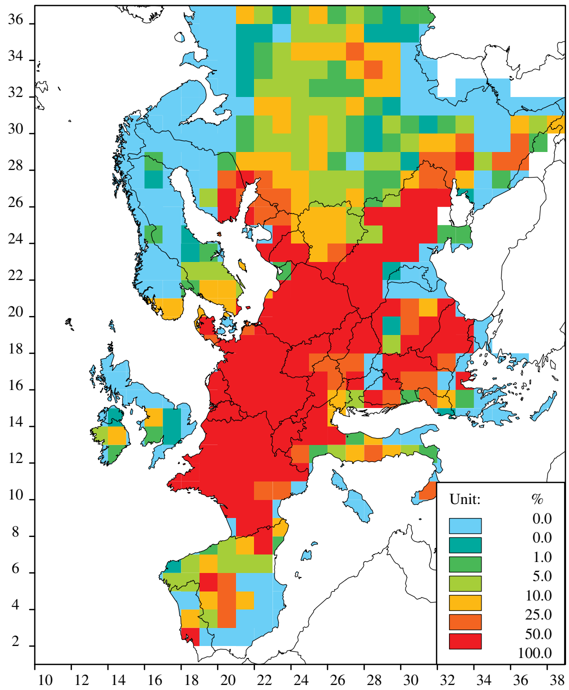


(a) for the emissions of 1990

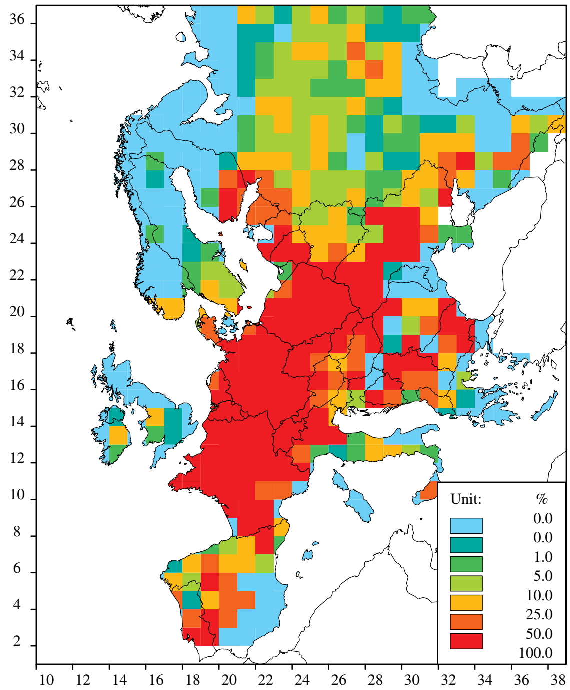


(b) for the Protocol emissions

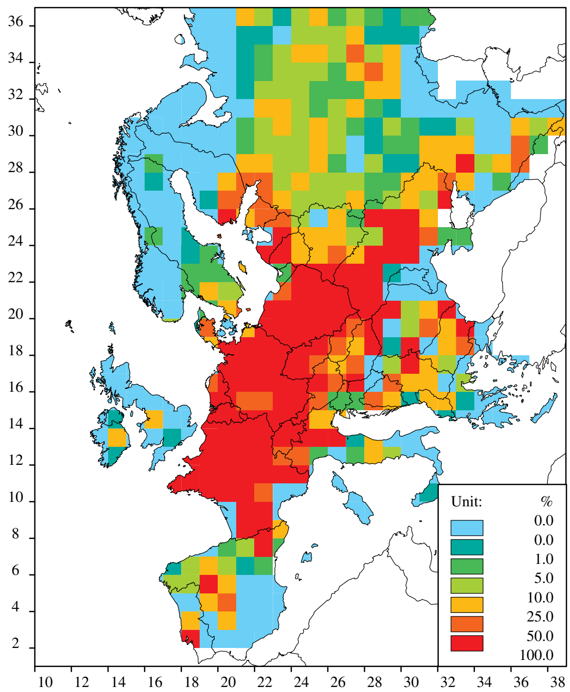
Figure 4.9: Percentage of ecosystems with nitrogen deposition above the critical loads



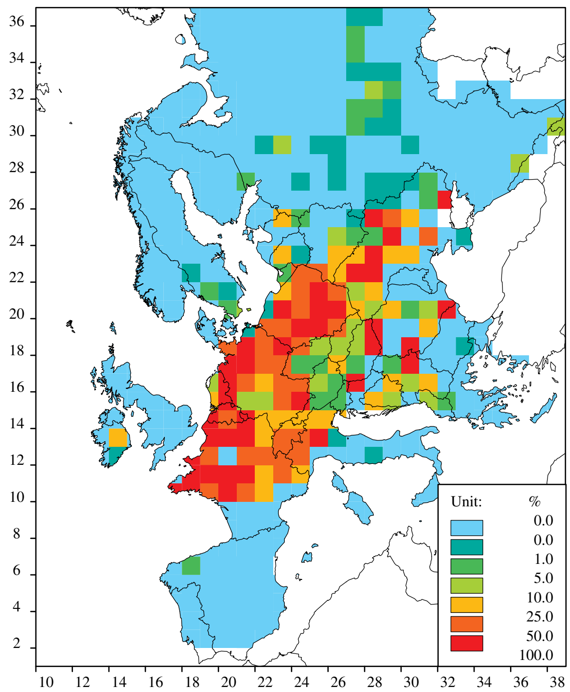
(a) REF scenario



(b) for the Protocol emissions



(c) G5/2_{rev} scenario



(d) MFR_{ult} scenario

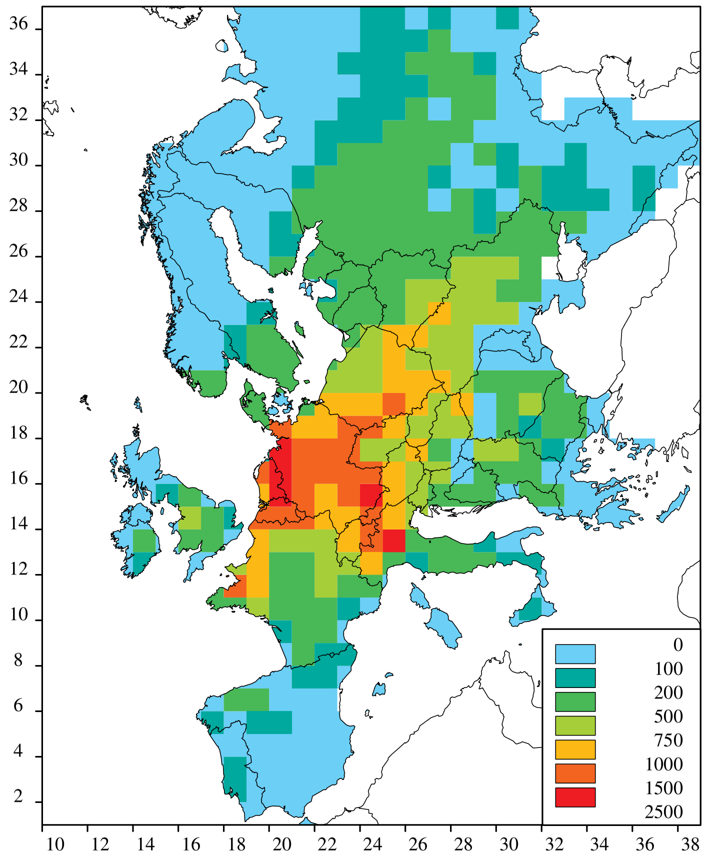
Figure 4.10 Percentage of ecosystems with nitrogen deposition above the critical loads

4.2.3 Total Excess Load

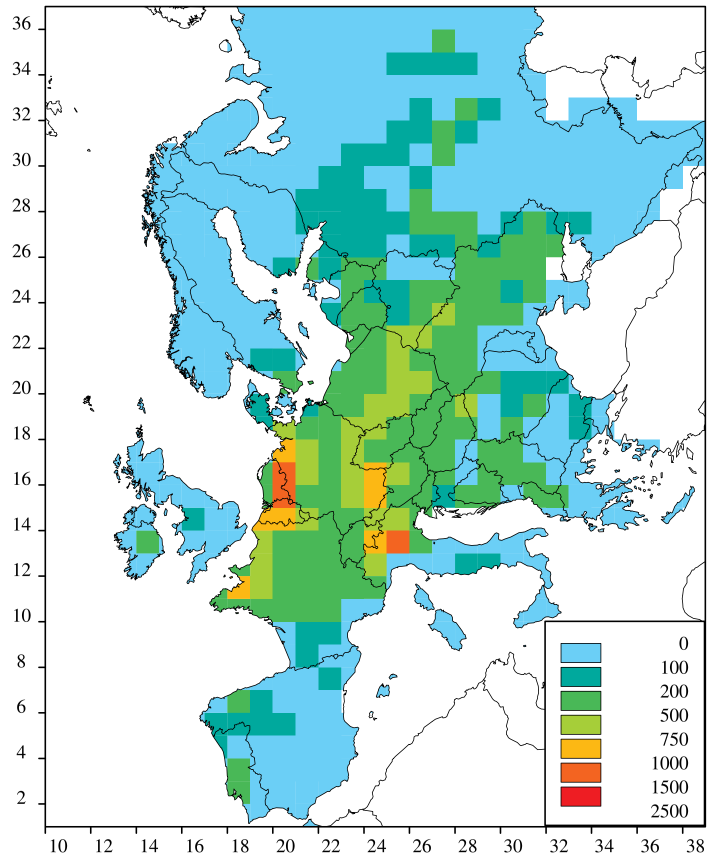
Table 4.4: Accumulated excess nitrogen deposition above the critical loads for eutrophication for 1990 and the Reference (REF), Protocol, revised G5/2 and hypothetical maximum technically feasible reductions (MFR_{ult}) scenarios.

	Total (million equivalents/year)					Average (equivalents/ha/year)				
	1990	REF	Protocol	G5/2rev	MFR_{ult}	1990	REF	Protocol	G5/2rev	MFR_{ult}
Austria	2488	860	725	400	76	416.8	144.0	121.4	67.0	12.8
Belgium	744	409	345	226	107	1059.1	582.4	490.5	321.4	152.6
Denmark	57	14	12	8	0	180.8	45.9	37.0	24.2	1.3
Finland	653	136	113	90	0	39.5	8.2	6.9	5.4	0.0
France	11756	7525	7413	4694	1592	370.0	236.9	233.3	147.8	50.1
Germany	8430	3450	3048	1731	427	821.7	336.3	297.1	168.7	41.6
Greece	27	13	8	6	0	10.9	5.4	3.3	2.5	0.1
Ireland	15	8	6	5	3	16.3	8.8	6.2	5.7	2.9
Italy	2495	1297	1150	764	293	208.2	108.2	96.0	63.7	24.4
Luxembourg	68	35	32	21	10	770.2	398.7	368.3	241.3	108.1
Netherlands	572	293	263	184	114	1789.6	917.4	821.4	575.9	357.4
Portugal	80	48	190	35	0	28.2	17.1	67.1	12.3	0.0
Spain	164	65	81	40	0	19.3	7.6	9.6	4.7	0.0
Sweden	364	77	74	46	2	19.4	4.1	4.0	2.5	0.1
UK	204	11	10	5	0	22.1	1.2	1.1	0.5	0.0
EU-15	28116	14242	13469	8254	2623	233.0	118.0	111.6	68.4	21.7
Albania	40	28	26	18	3	37.5	26.7	24.5	17.3	2.6
Belarus	632	303	238	190	45	125.7	60.3	47.4	37.7	9.0
Bosnia-H	249	99	79	51	6	172.0	68.4	54.3	35.3	4.3
Bulgaria	673	352	170	110	5	136.1	71.2	34.4	22.3	1.0
Croatia	11	3	1	1	0	42.0	9.2	5.2	2.0	0.0
Czech Rep.	1632	762	627	452	51	614.1	286.9	235.9	170.3	19.3
Estonia	248	115	111	95	0	131.1	60.8	58.5	50.0	0.2
Hungary	94	80	62	50	28	330.6	282.4	217.5	176.6	97.0
Latvia	497	226	233	153	1	182.9	83.3	85.7	56.2	0.4
Lithuania	448	246	222	150	2	236.5	129.7	116.9	78.9	1.3
Norway	271	7	4	1	0	19.4	0.5	0.3	0.1	0.0
Poland	10008	6330	4919	4077	989	576.9	364.9	283.6	235.0	57.0
R.of Moldova	0	0	0	0	0	0.1	0.0	0.0	0.0	0.0
Romania	899	678	414	367	130	144.2	108.8	66.4	58.9	20.8
Russia	5710	2252	1937	1806	43	16.5	6.5	5.6	5.2	0.1
Slovakia	738	352	224	157	17	367.8	175.2	111.6	78.2	8.3
Slovenia	110	37	29	19	5	121.6	40.9	32.0	21.1	5.2
Switzerland	1139	591	524	356	96	499.9	259.1	230.1	156.0	42.2
FYR of Maced.	33	21	18	12	2	30.6	19.3	16.8	11.3	2.0
Ukraine	2413	1462	1108	967	197	292.9	177.4	134.4	117.3	23.9
Yugoslavia	711	475	414	290	125	208.5	139.1	121.4	85.1	36.5
Non-EU	26556	14419	11360	9321	1745	62.6	34.0	26.8	22.0	4.1
Total	54672	28660	24829	17575	4368	100.4	52.6	45.6	32.3	8.0

4.2.4 Excess Deposition over 2-Percentile Critical load

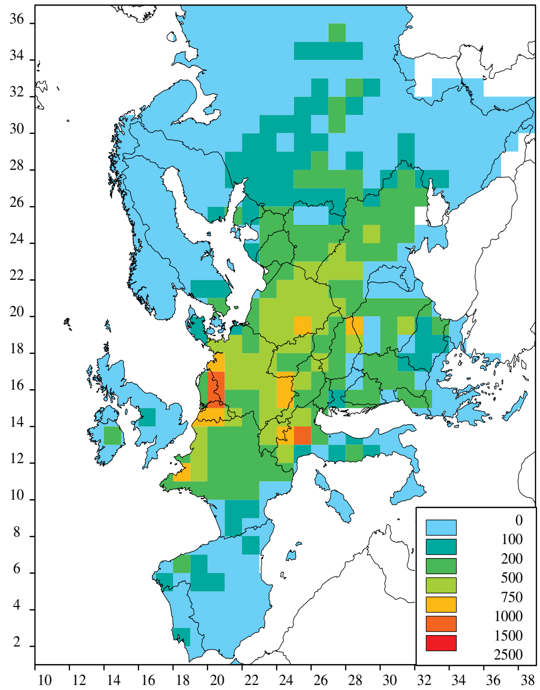


(a) for the emissions of 1990

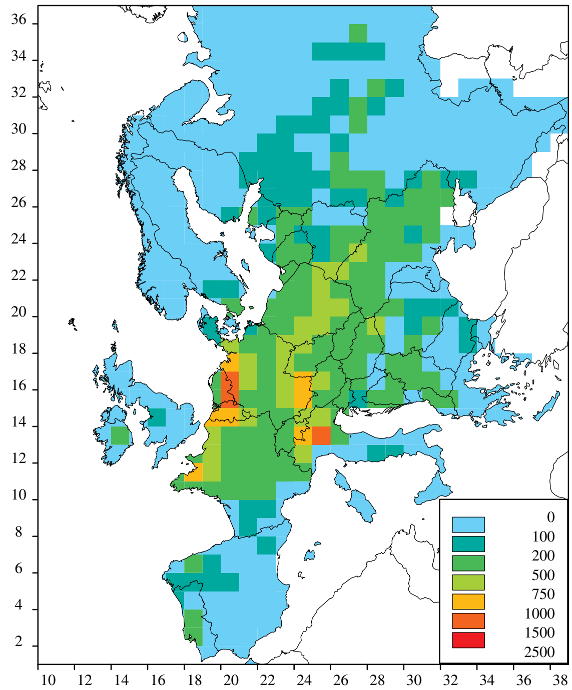


(b) for the Protocol emissions

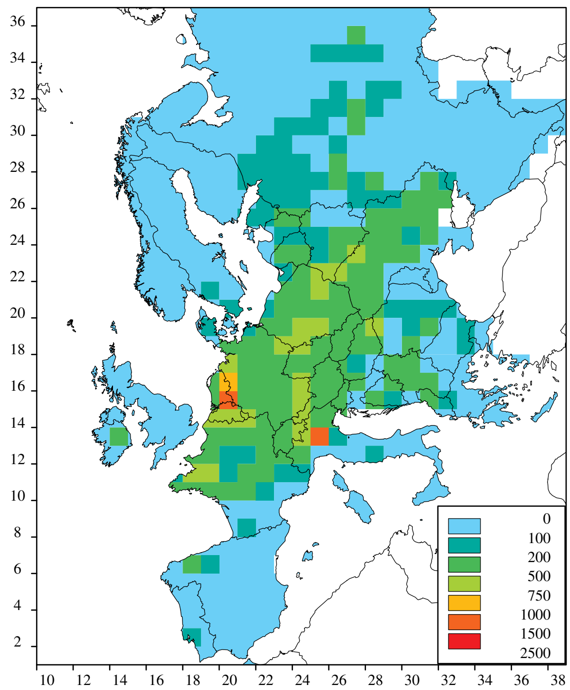
Figure 4.11: Excess nitrogen deposition over the 2-percentile critical load for eutrophication (equivalents/ha/year)



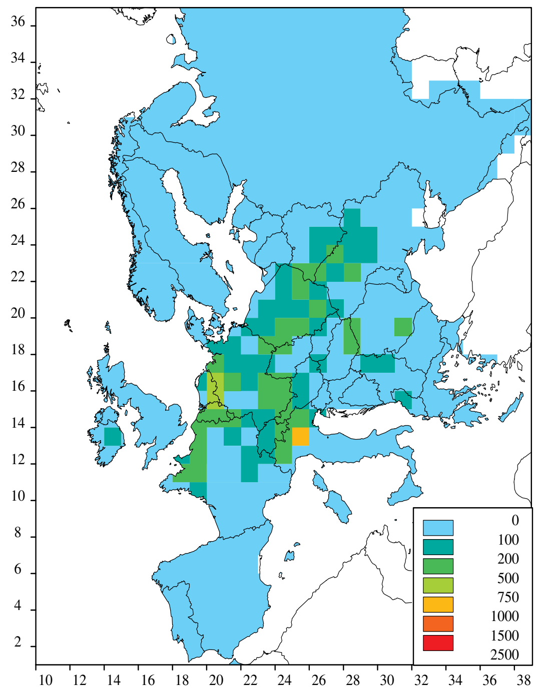
(a) REF scenario



(b) for the Protocol emissions



(c) G5/2_{rev} scenario



(d) MFR_{ult} scenario

Figure 4.12: Excess nitrogen deposition over the 2-percentile critical load for eutrophication (equivalents/ha/year)

4.3 Ozone

There are several statistics against which improvement in ozone exposure could be evaluated. This report provides the following analyses:

- In order to present the improvements in generally understandable notions, maps indicate the number of days on which the WHO health guideline (60 ppb) is exceeded. Figure 4.13-Figure 4.14 present, for each of the four scenarios, the maximum of the three-year moving averages over the five years considered.
- A second series of maps (Figure 4.15 - Figure 4.16) shows the number of days on which ozone concentrations exceed 90 ppb. The data are again given in terms of the maximum of the three-year moving averages.
- The third series of maps indicates the few grids at which ozone concentrations exceed 120 ppb (Figure 4.17 (a-d)).
- A fourth series of maps shows the AOT60 values, which were used as a surrogate health-risk indicator in the optimisation calculations. For the AOT60, the second highest value out of the five years is presented (Figure 4.18 - Figure 4.19).
- Table 4.5 provides a comparison of the population exposure indices calculated for the four scenarios.
- The final series of maps (Figure 4.20 - Figure 4.21) presents five-year mean AOT40 values for the four scenarios.
- Vegetation exposure indices are given in Table 4.6.

Figure 4.13(a) displays the number of days on which the WHO health guideline value (60 ppb, eight-hour moving average) was exceeded with the 1990 emissions. The map shows the maximum of the three-year moving averages over the meteorological conditions of the five available years. Most frequent excess is calculated for Italy (about 60 days), while northern France experienced about 50 days and Germany 30-40 days. Spain and Portugal, Greece, Ireland and the UK are mainly between 10 and 20, while Scandinavia shows typically below 10 days excess.

The emission controls calculated for the REF scenario are expected to have profound impacts on ozone exposure. The maximum number of violations is expected to decline to 35 in France, about 30 in Italy and approximately 25 in Germany (Figure 4.14a). In the revised G5/2 scenario (Figure 4.14c) the number of days in excess of 60 ppb is expected to fall still further, with a maximum of about 25 days in Belgium/northern France.

For comparison, Figure 4.15 - Figure 4.16 present the situation for days exceeding a 90 ppb concentration. While in 1990 the maximum was about 12 days in northern France, the frequency is expected to decline to about 4 days in the REF scenario and 3 days for the emissions of the revised G5/2 scenario, both of these occurring in the Benelux region. No more than one day a year in excess of 90 ppb would be expected in the MFR_{ult} scenario.

The series of maps showing the grids at which ozone concentrations exceed 120 ppb (Figure 4.17a-d) indicates a maximum number of 4 days in the Benelux region for the emissions of 1990. There are very few grids with any excess of this threshold in the REF and revised G5/2 scenarios. For the emissions of the MFR_{ult} scenario, no days with ozone in excess of 120 ppb are expected.

Figure 4.18(a) illustrates that for the emissions of 1990 and using the meteorological conditions of five years, the second highest (rural) AOT60 of more than 9 ppm.hours occurred in northern France, Belgium and Germany. In many other parts of France, Germany and Benelux, the AOT60 was modelled in a range of 7-8 ppm.hours. Typical rural values in the UK and Austria were between 2 and 3 ppm.hours, while the peak AOT60 values in Spain and Greece were between 1 and 2 ppm.hours. Portugal is estimated at 2 ppm.hours, while Scandinavia did not experience significant excess of the AOT60.

With the emissions of the REF scenario, the AOT60 (second highest occurrence of the five years) peaks at a value less than 5 ppm.hours in two grids on the border of Belgium, France and Luxembourg (Figure 4.19a). For the further emission reductions of the revised G5/2 scenario, the maximum AOT60 value is found in the same region but now reduced below 3 ppm.hours (Figure 4.19c). In comparison, the Protocol (Figure 4.19b) will leave this area with an AOT60 of about 3.7 ppm.hours.

Table 4.5 presents two different types of population exposure for AOT60. The cumulative index reflects for each country the total exposure of a population and is expressed in person.ppm.hours. These indices are calculated on a grid basis (using gridded data on AOT60 and population); in a second step these grid values are aggregated to the country level. The indices presented in this report use the AOT60 concentrations per grid, representing the rural ozone concentrations, and the total population per grid in 1990. The 'average' indicator reflects the average exposure of a person in a country, calculated from gridded data. It is important to stress that these indices may not be used to derive estimates of health damage, for which more detailed information is deemed necessary. In the context of this report, these indices provide relative measures to enable comparisons between different scenarios.

As shown in the table, in 1990 the average exposure was highest in Luxembourg, Belgium, France, Germany and the Netherlands; the highest cumulative exposure (due to the large population) occurred in Germany, France, Italy and the UK. The cumulative exposure of the population in Europe is expected to decline from 1990 levels by 64 percent as a result of current policy, and by 78 percent if the emission reductions of the revised G5/2 scenario were implemented. For the Protocol, a 69 percent improvement of this indicator is calculated.

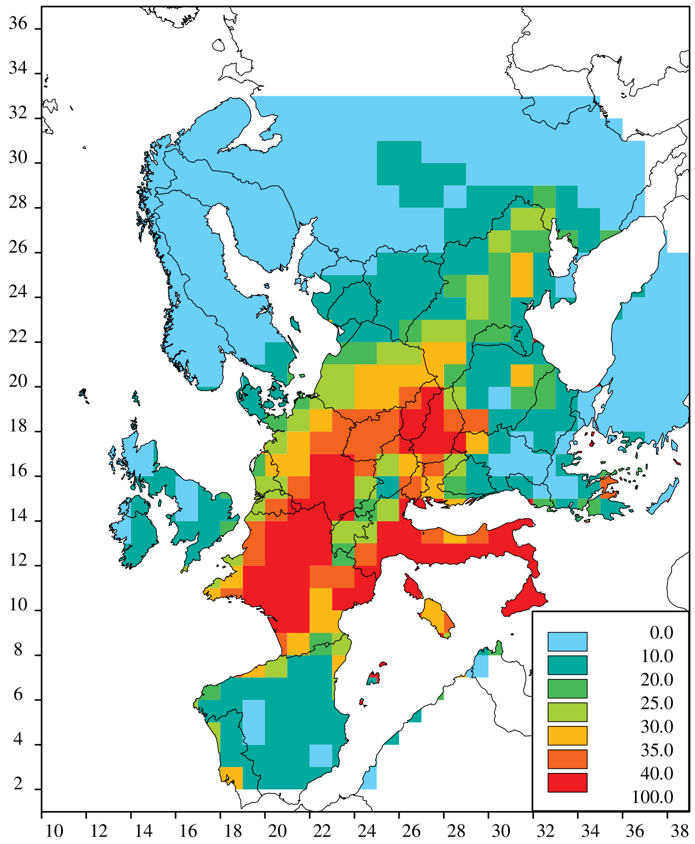
Figure 4.20(a) displays the AOT40 calculated for the emissions of the year 1990 using the five-year mean meteorology. The map clearly shows that in most countries the critical level for vegetation (3 ppm.hours) was exceeded. The only exceptions occur in parts of the Scandinavian countries and parts of Russia. In an area extending across France through Belgium to Germany the AOT40 exceeded 15 ppm.hours, reaching a maximum of about 20 ppm.hours in the centre of this area. It is noteworthy that ozone levels in many areas that do not experience significant excess of the AOT60 do exceed the AOT40 criterion by a considerable margin. This applies particularly to the Mediterranean countries and some Alpine regions.

The emission reductions of the Reference scenario will generally lead to a decline in AOT40, but will not significantly increase the protected area (Figure 4.21a). Peak levels lie in the range of 12-15 ppm.hours. The revised G5/2 scenario reduces the maximum AOT40 level to 13 ppm.hours in France and northern Italy (Figure 4.21c), and the Protocol will result in somewhat higher exposure.

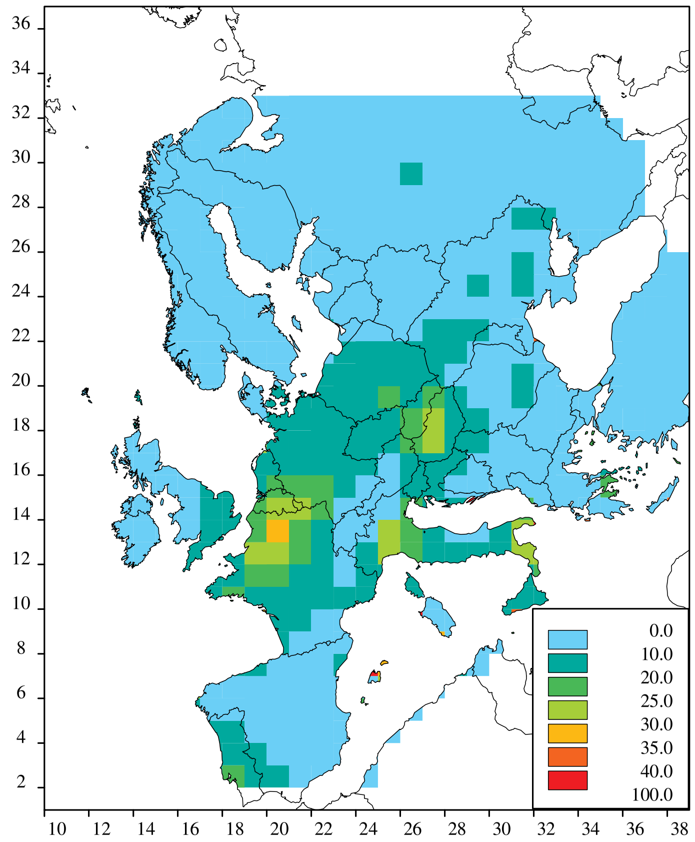
Table 4.6 provides two vegetation-related exposure indices. The cumulative vegetation exposure index is calculated as the excess AOT40 (i.e., the AOT40 in excess of the critical level of 3 ppm.hours) multiplied by the area of ecosystems that is exposed to the excess concentration. The index is calculated on a grid resolution, considering agricultural land, natural vegetation and forest areas. The average vegetation exposure index reflects the average excess AOT40 (over all grids in a country) weighted by ecosystem area. The estimate of these indices is based on rural ozone concentrations.

The highest average excess exposure for the revised G5/2 scenario as well as for the Protocol occurs in Belgium, Luxembourg, Italy and France. In absolute terms, France, Spain, Italy and Germany will continue to have the highest cumulative exposure for their ecosystems.

4.3.1 Days with Ozone above 60 ppb

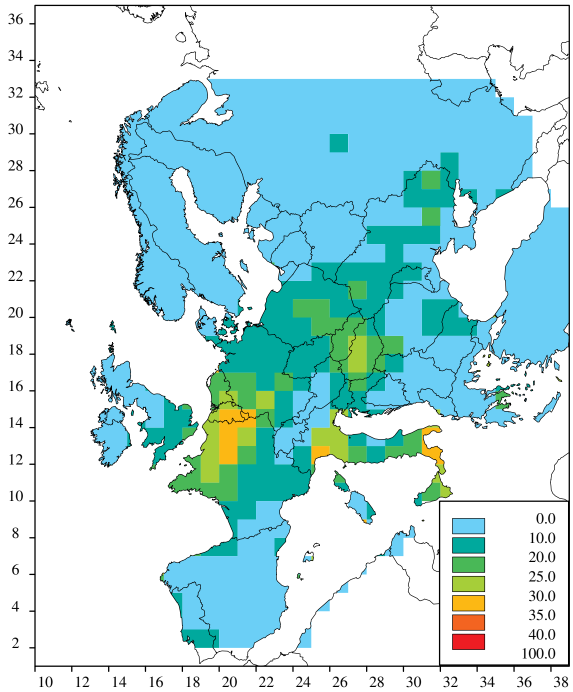


(a) for the emissions of 1990

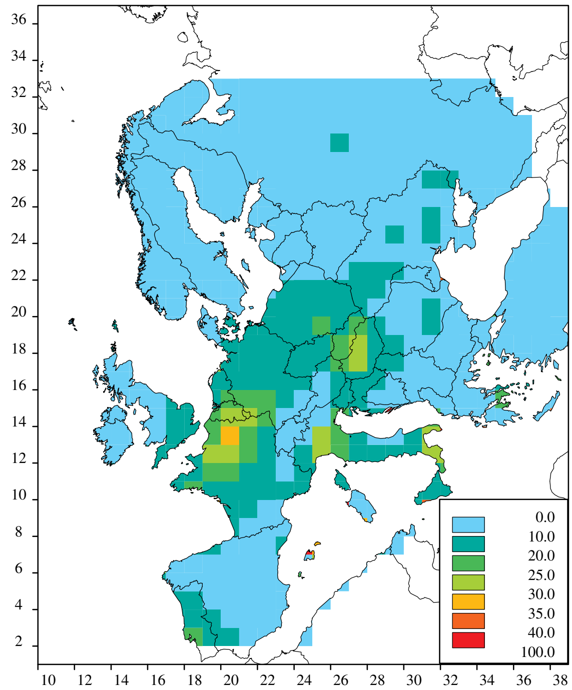


(b) for the Protocol emissions

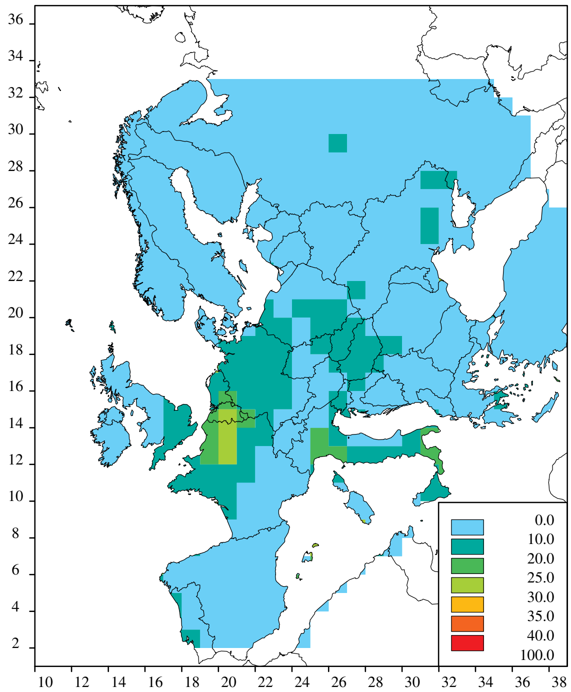
Figure 4.13: Number of days with ozone in excess of 60 ppb - maximum of the three-year moving averages. An ozone concentration of 60 ppb is equivalent to 120 µg m^{-3}, the unit in which the WHO 8-hour air quality guideline for ozone is expressed.



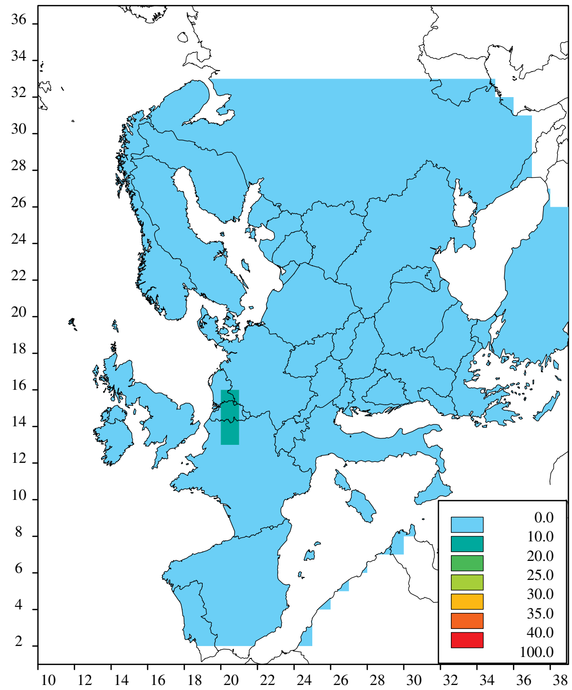
(a) REF scenario



(b) for the Protocol emissions



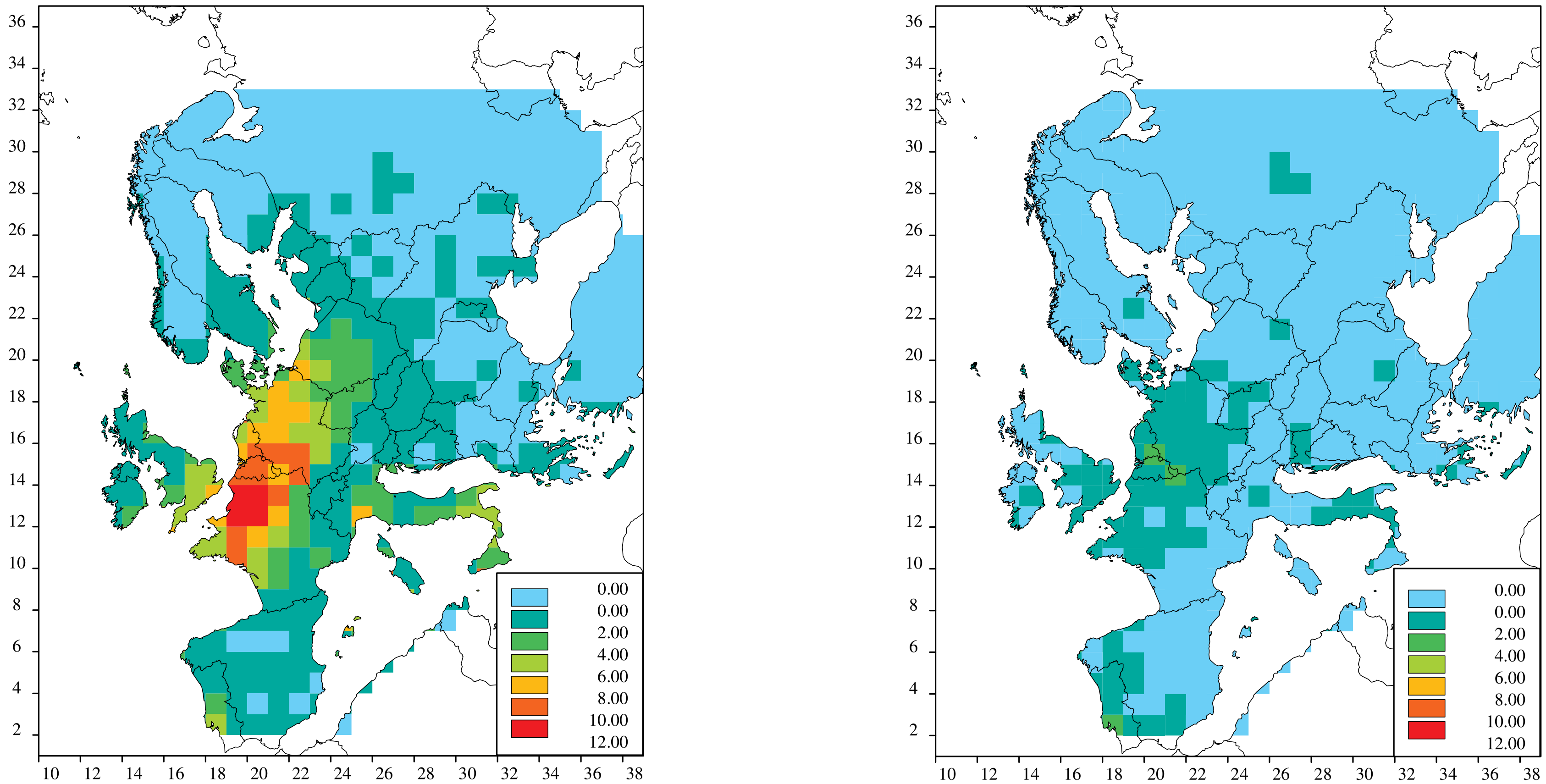
(c) G5/2_{rev} scenario



(d) MFR_{ult} scenario

Figure 4.14: Number of days with ozone in excess of 60 ppb - maximum of the three-year moving averages

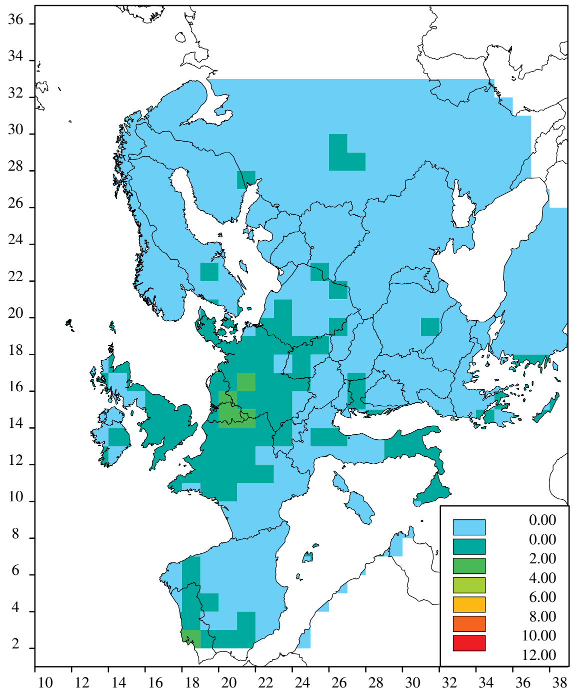
4.3.2 Days with Ozone above 90 ppb



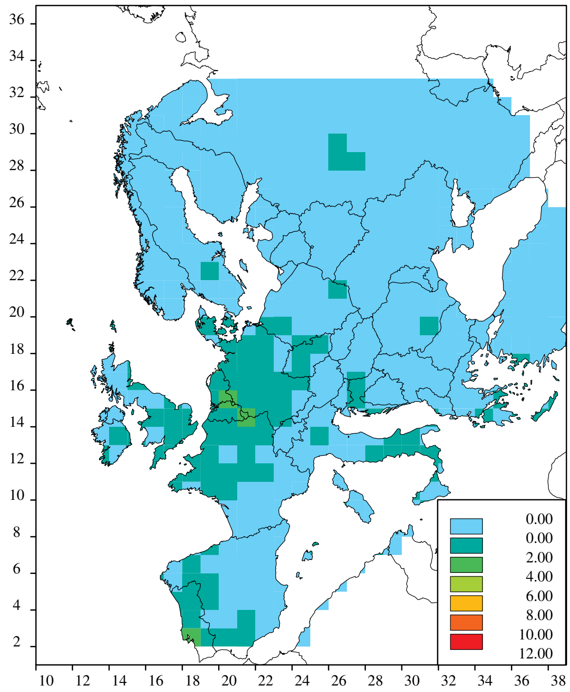
(a) for the emissions of 1990

(b) for the Protocol emissions

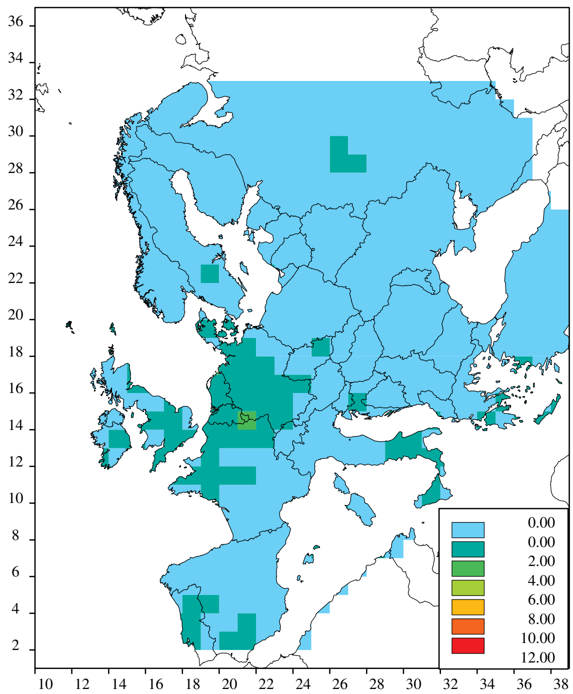
Figure 4.15: Number of days with ozone in excess of 90 ppb - maximum of the three-year moving averages



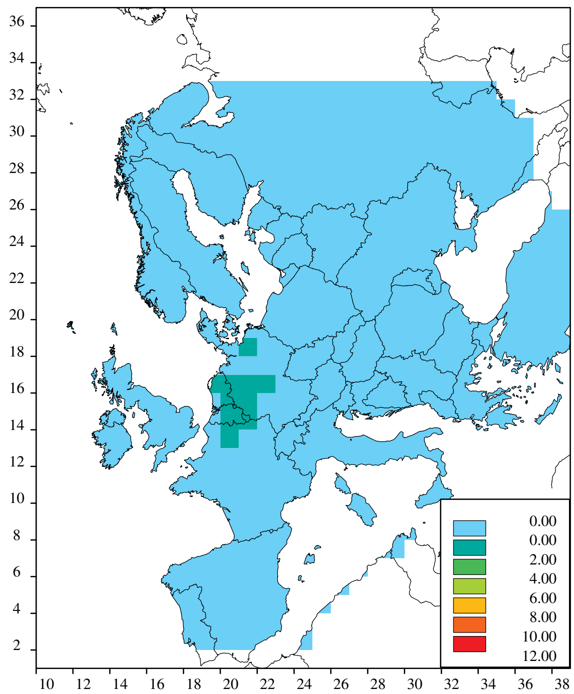
(a) REF scenario



(b) for the Protocol emissions



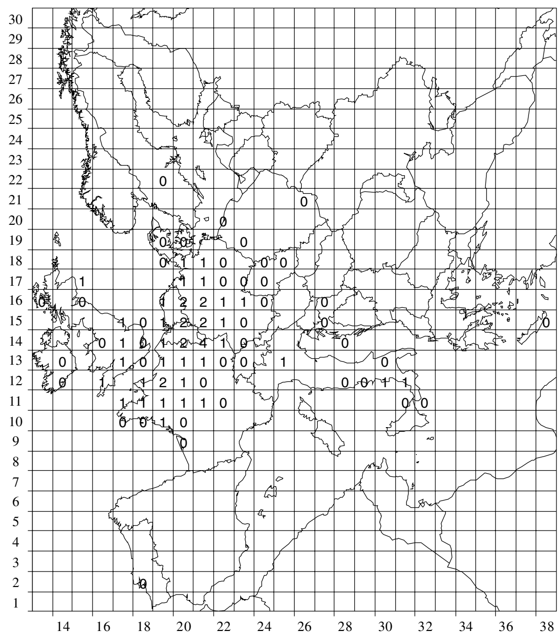
(c) G5/2$_{rev}$ scenario



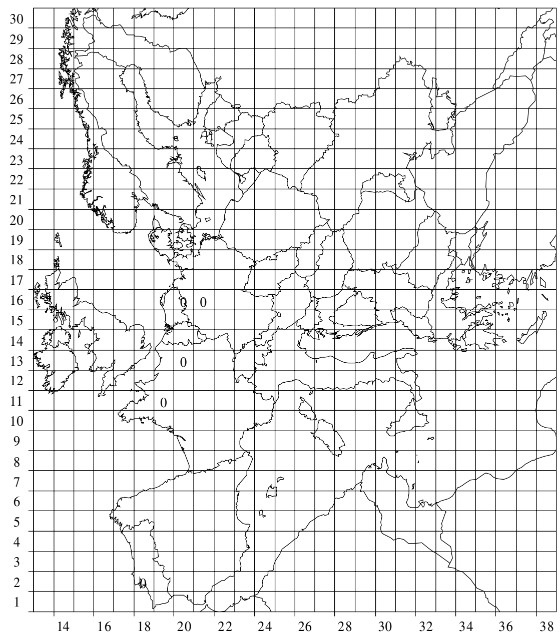
(d) MFR$_{ult}$ scenario

Figure 4.16: Number of days with ozone in excess of 90 ppb - maximum of the three-year moving averages

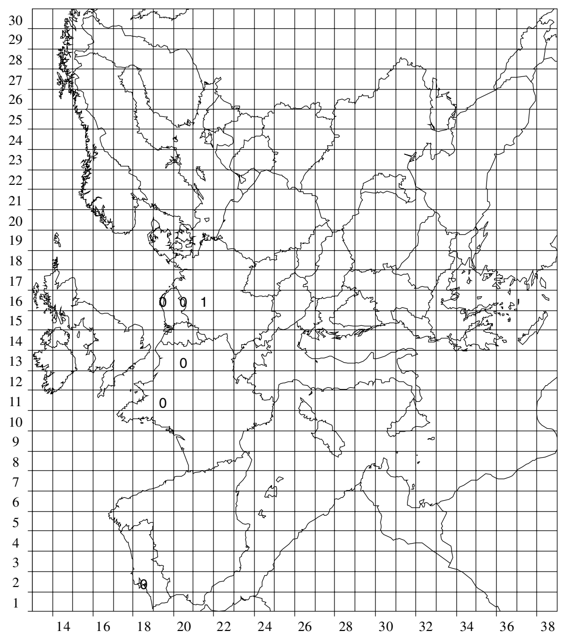
4.3.3 Days with Ozone above 120 ppb



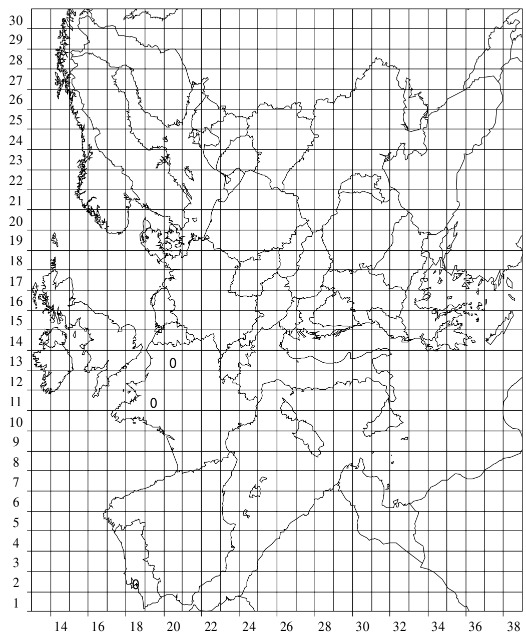
(a) for the emissions of 1990



(b) for the Protocol emissions



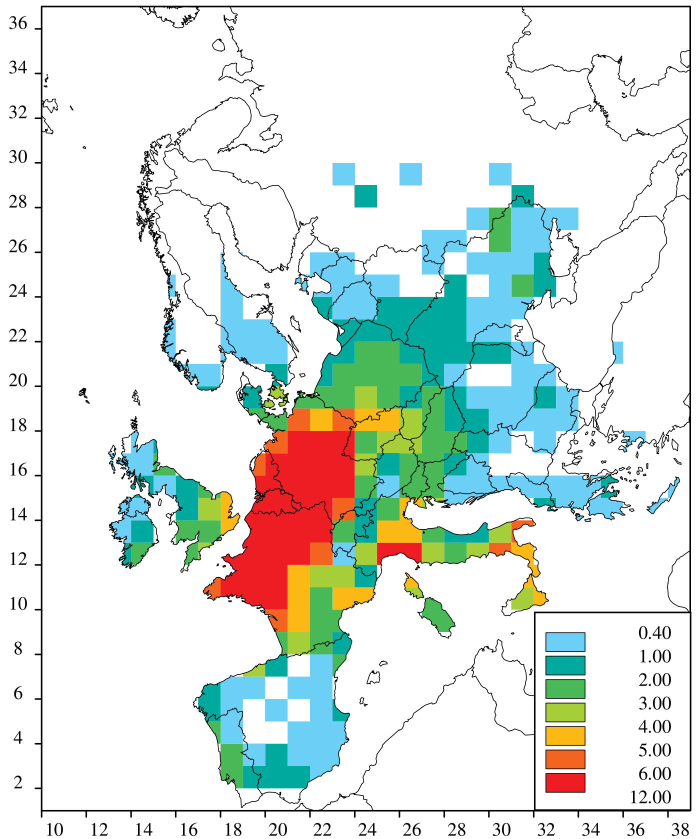
(c) REF scenario



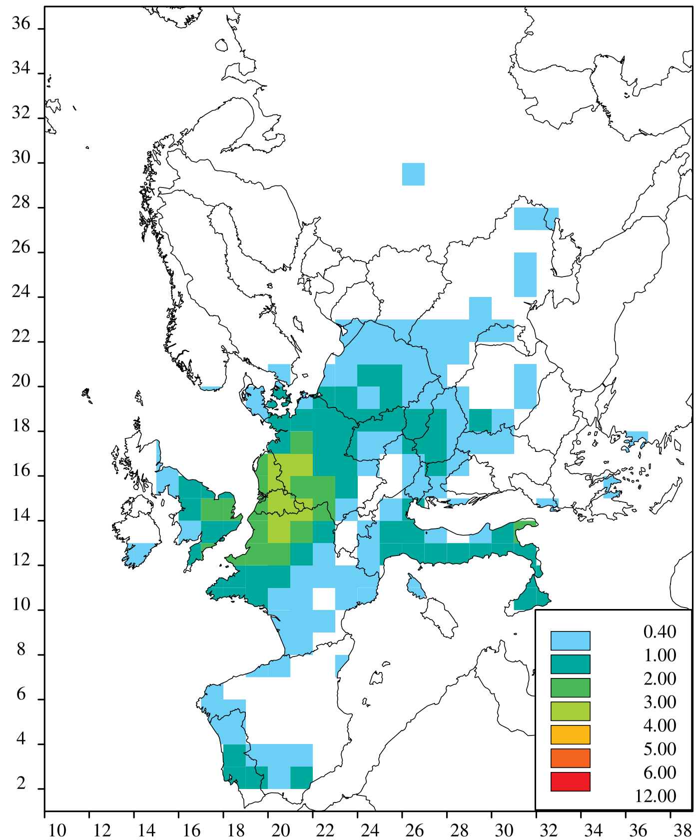
(d) G5/2$_{rev}$ scenario

Figure 4.17: Number of days with ozone in excess of 120 ppb - maximum of the three-year moving averages

4.3.4 AOT60

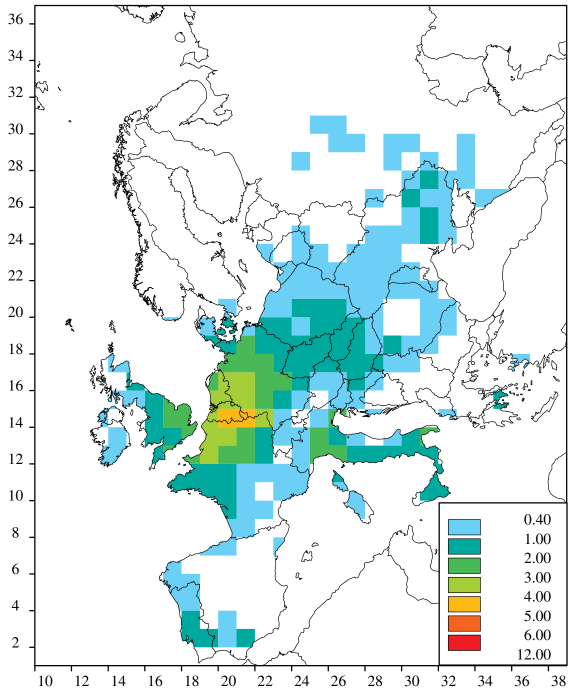


(a) for the emissions of 1990

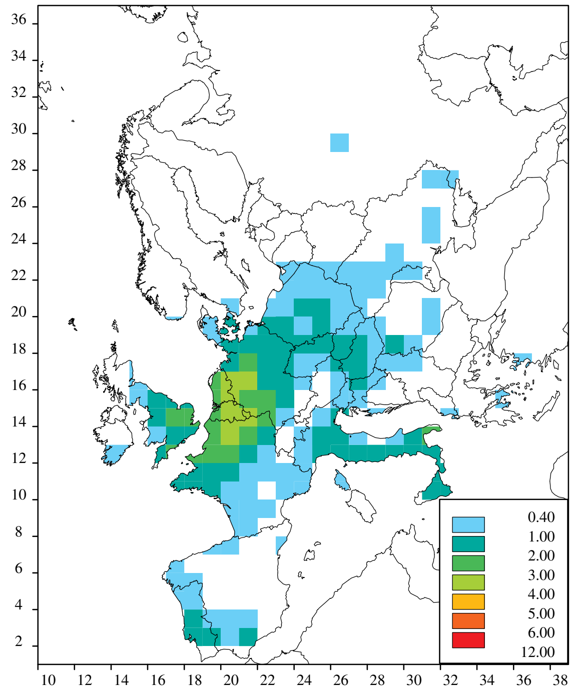


(b) for the Protocol emissions

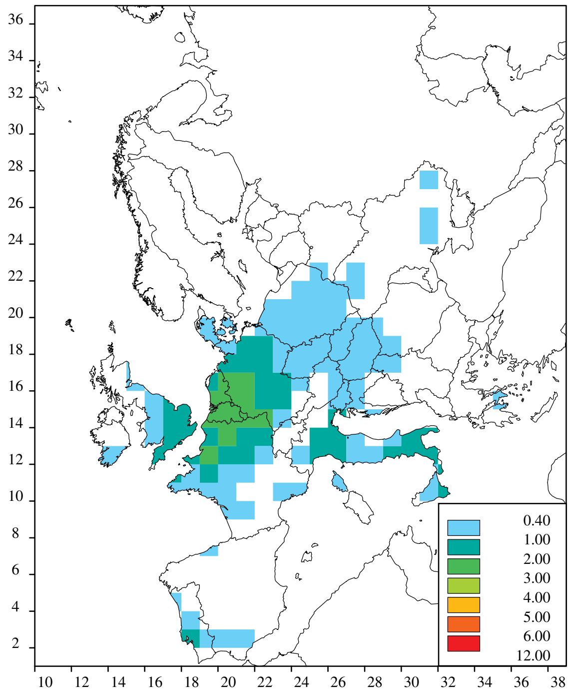
Figure 4.18: AOT60 (second highest occurrence in five meteorological years); in ppm.hours



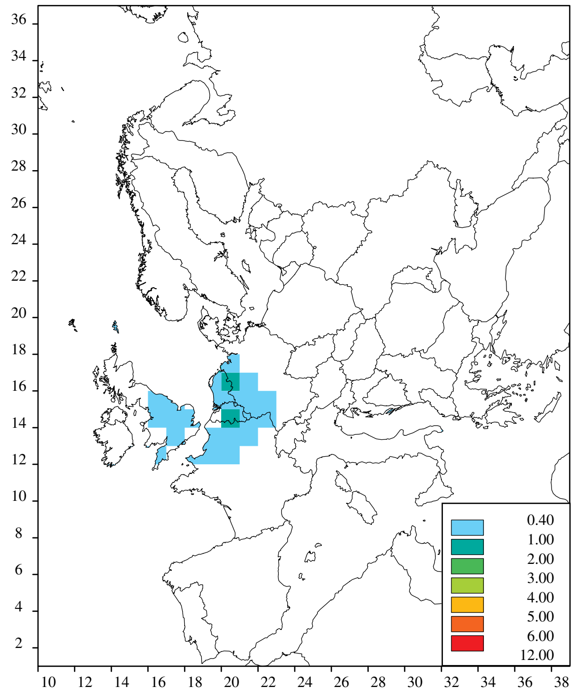
(a) REF scenario



(b) for the Protocol emissions



(c) G5/2_{rev} scenario



(d) MFR_{ult} scenario

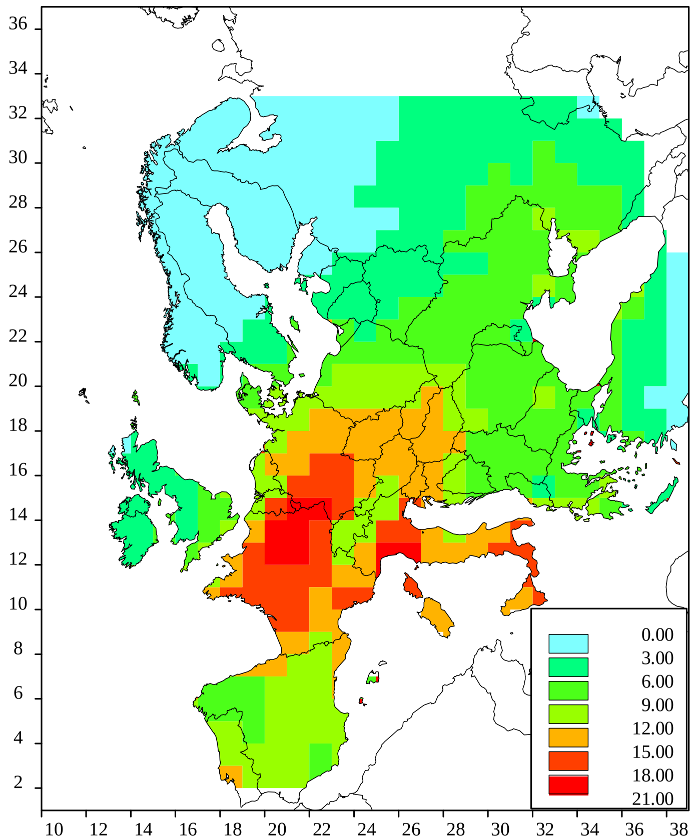
Figure 4.19: AOT60 (second highest occurrence in five meteorological years); in ppm.hours

4.3.5 Population Exposure Indices

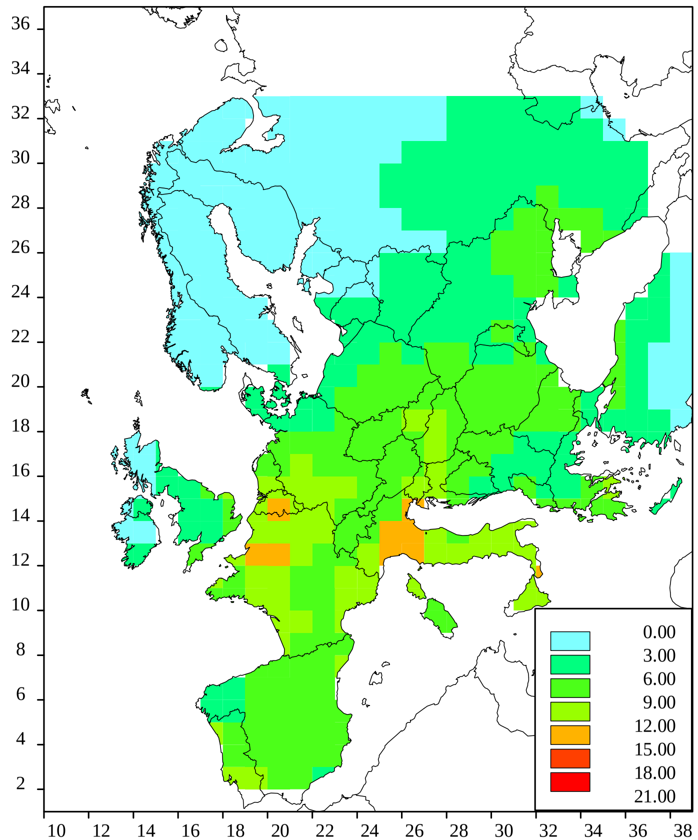
Table 4.5: Population exposure indices for the emissions of 1990 and the Reference (REF), Protocol, revised G5/2 and hypothetical maximum technically feasible reductions (MFR_{ult}) scenarios.

	Cumulative population exposure index (million persons.ppm.hours)					Average population exposure index (ppm.hours)				
	1990	REF	Protocol	G5/2rev	MFR_{ult}	1990	REF	Protocol	G5/2rev	MFR_{ult}
Austria	16	3	2	1	0	2.0	0.5	0.3	0.2	0.0
Belgium	71	34	29	22	7	6.5	3.1	2.6	2.1	0.6
Denmark	9	3	2	1	0	1.8	0.5	0.4	0.2	0.0
Finland	0	0	0	0	0	0.1	0.0	0.0	0.0	0.0
France	311	89	75	54	9	5.5	1.6	1.3	1.0	0.2
Germany	404	140	118	91	17	5.1	1.8	1.5	1.1	0.2
Greece	7	4	3	3	0	0.7	0.4	0.3	0.3	0.0
Ireland	3	1	1	0	0	0.8	0.3	0.2	0.1	0.0
Italy	183	63	55	40	0	3.2	1.1	1.0	0.7	0.0
Luxembourg	3	1	1	1	0	8.5	3.0	2.6	2.1	0.6
Netherlands	73	38	32	26	9	4.9	2.6	2.2	1.8	0.6
Portugal	16	8	9	6	0	1.6	0.8	0.9	0.6	0.0
Spain	35	7	7	3	0	0.9	0.2	0.2	0.1	0.0
Sweden	4	0	0	0	0	0.4	0.0	0.0	0.0	0.0
UK	125	77	63	49	12	2.2	1.3	1.1	0.9	0.2
EU-15	1260	466	398	298	53	3.5	1.3	1.1	0.8	0.1
Albania	1	0	0	0	0	0.4	0.0	0.0	0.0	0.0
Belarus	4	1	0	0	0	0.4	0.1	0.0	0.0	0.0
Bosnia-H	3	0	0	0	0	0.7	0.1	0.1	0.0	0.0
Bulgaria	4	1	0	0	0	0.4	0.1	0.0	0.0	0.0
Croatia	8	3	3	1	0	1.8	0.6	0.5	0.3	0.0
Czech Rep.	34	11	9	5	0	3.3	1.0	0.9	0.5	0.0
Estonia	0	0	0	0	0	0.2	0.0	0.0	0.0	0.0
Hungary	27	12	10	6	0	2.6	1.1	1.0	0.6	0.0
Latvia	1	0	0	0	0	0.4	0.1	0.0	0.0	0.0
Lithuania	2	0	0	0	0	0.6	0.1	0.1	0.0	0.0
Norway	1	0	0	0	0	0.1	0.0	0.0	0.0	0.0
Poland	91	36	30	18	0	2.4	0.9	0.8	0.5	0.0
R.of Moldova	3	1	1	0	0	0.7	0.2	0.1	0.1	0.0
Romania	17	6	4	1	0	0.8	0.3	0.2	0.0	0.0
Russia	21	7	5	5	0	0.2	0.1	0.1	0.0	0.0
Slovakia	15	6	5	3	0	2.8	1.1	1.0	0.6	0.0
Slovenia	4	1	1	1	0	2.3	0.7	0.6	0.4	0.0
Switzerland	14	2	1	1	0	2.1	0.3	0.2	0.1	0.0
FYR of Maced.	0	0	0	0	0	0.1	0.0	0.0	0.0	0.0
Ukraine	45	14	8	6	0	0.9	0.3	0.2	0.1	0.0
Yugoslavia	8	3	2	1	0	0.7	0.2	0.2	0.1	0.0
Non-EU	305	103	82	48	0	1.0	0.3	0.3	0.2	0.0
Total	1566	570	480	346	53	2.3	0.8	0.7	0.5	0.1

4.3.6 AOT40

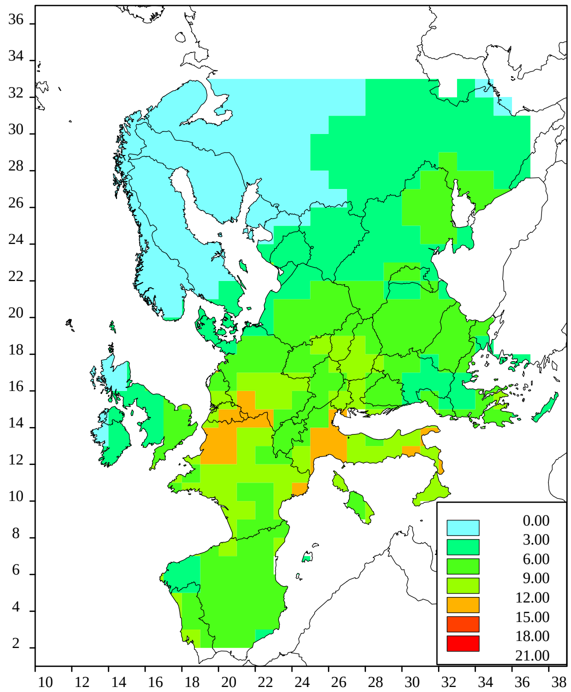


(a) for the emissions of 1990

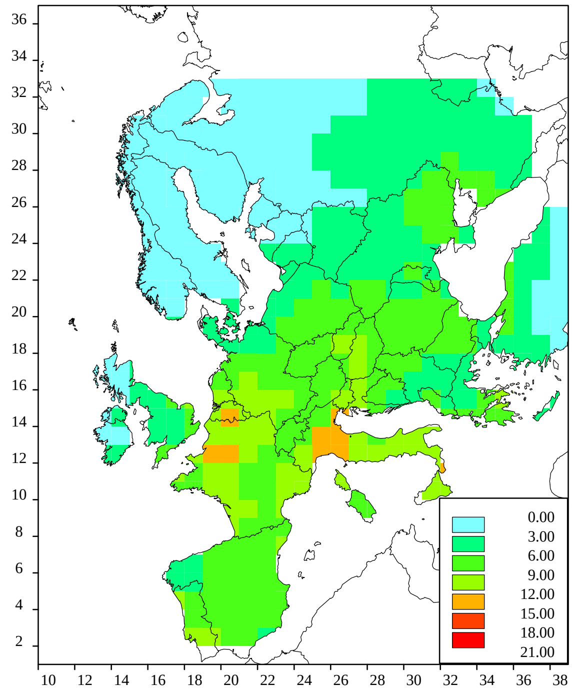


(b) for the Protocol emissions

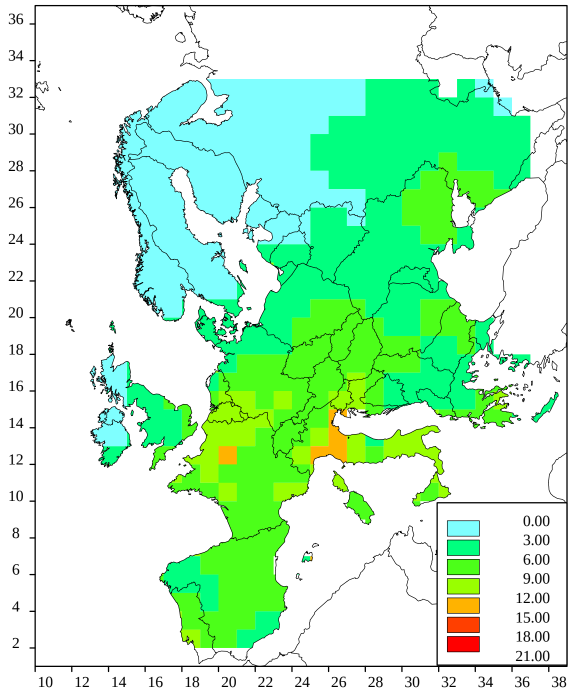
Figure 4.20: AOT40 (in ppm.hours)



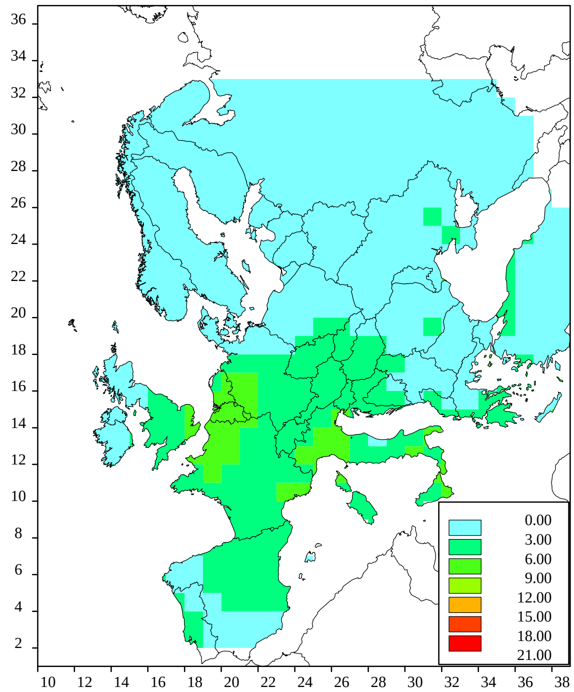
(a) REF scenario



(b) for the Protocol emissions



(c) $G5/2_{rev}$ scenario



(d) MFR_{ult} scenario

Figure 4.21: AOT40 (in ppm.hours)

4.3.7 Vegetation Exposure Indices

Table 4.6: Vegetation exposure indices for the emissions of 1990 and the Reference (REF), Protocol, revised G5/2 and hypothetical maximum technically feasible reductions (MFR_{ult}) scenarios.

	Cumulative vegetation exposure index (1000 km^2.excess ppm.hours)					Average vegetation exposure index (excess ppm.hours)				
	1990	REF	Protocol	G5/2rev	MFR_{ult}	1990	REF	Protocol	G5/2rev	MFR_{ult}
Austria	468	257	238	194	37	9.0	5.0	4.6	3.7	0.7
Belgium	177	141	130	115	82	11.4	9.1	8.4	7.4	5.3
Denmark	160	53	43	30	0	5.3	1.8	1.4	1.0	0.0
Finland	0	0	0	0	0	0.0	0.0	0.0	0.0	0.0
France	4168	2345	2201	1865	743	12.9	7.3	6.8	5.8	2.3
Germany	2341	1204	1064	901	340	11.0	5.7	5.0	4.2	1.6
Greece	245	170	160	146	9	4.5	3.1	3.0	2.7	0.2
Ireland	29	8	5	3	0	1.3	0.3	0.2	0.1	0.0
Italy	1852	1186	1125	993	422	11.8	7.5	7.1	6.3	2.7
Luxembourg	25	14	13	11	5	16.5	9.3	8.7	7.4	3.5
Netherlands	110	79	71	63	42	8.5	6.1	5.4	4.8	3.3
Portugal	383	274	290	229	24	6.6	4.7	5.0	4.0	0.4
Spain	2088	1281	1325	1046	99	6.8	4.2	4.3	3.4	0.3
Sweden	163	18	11	7	0	0.5	0.1	0.0	0.0	0.0
UK	204	153	129	111	72	2.5	1.9	1.6	1.4	0.9
EU-15	12412	7183	6804	5714	1875	6.6	3.8	3.6	3.1	1.0
Albania	82	56	53	46	3	4.8	3.3	3.1	2.7	0.2
Belarus	186	78	50	44	0	2.1	0.9	0.6	0.5	0.0
Bosnia-H	244	162	152	126	11	6.4	4.2	4.0	3.3	0.3
Bulgaria	357	281	259	228	0	4.8	3.8	3.5	3.0	0.0
Croatia	347	214	202	173	45	9.7	6.0	5.7	4.9	1.3
Czech Rep.	570	311	279	218	36	10.2	5.6	5.0	3.9	0.7
Estonia	2	0	0	0	0	0.1	0.0	0.0	0.0	0.0
Hungary	631	404	377	290	22	9.7	6.2	5.8	4.5	0.3
Latvia	42	6	4	2	0	1.0	0.1	0.1	0.0	0.0
Lithuania	77	23	13	9	0	1.8	0.6	0.3	0.2	0.0
Norway	4	1	1	1	0	0.0	0.0	0.0	0.0	0.0
Poland	1510	829	734	529	8	6.6	3.6	3.2	2.3	0.0
R.of Moldova	83	56	56	43	0	4.9	3.3	3.3	2.5	0.0
Romania	845	623	580	458	1	5.4	4.0	3.7	2.9	0.0
Russia	1764	983	901	861	0	0.9	0.5	0.5	0.4	0.0
Slovakia	341	215	198	153	11	9.6	6.0	5.5	4.3	0.3
Slovenia	139	94	90	78	25	10.7	7.2	6.9	5.9	1.9
Switzerland	155	85	79	70	25	8.7	4.8	4.5	3.9	1.4
FYR of Maced.	52	40	37	33	0	3.3	2.5	2.4	2.1	0.0
Ukraine	1776	1206	1098	971	5	4.5	3.1	2.8	2.5	0.0
Yugoslavia	327	248	233	195	6	4.8	3.7	3.4	2.9	0.1
Non-EU	9535	5916	5396	4526	199	2.7	1.7	1.6	1.3	0.1
Total	21946	13099	12200	10240	2074	4.1	2.5	2.3	1.9	0.4

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